CHAMBERS'S

SCIENCE MANUALS

ANIMAL PHYSIOLOGY

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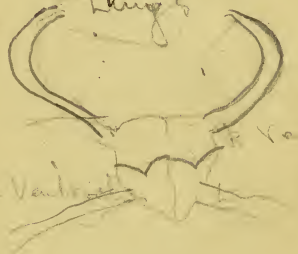

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CHAMBERS'S
ELEMENTARY SCIENCE MANUALS.

ANIMAL PHYSIOLOGY

BY

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GENERAL PLAN OF THE SERIES.

THE subjects of these Manuals are for the most part, though not exclusively, the same as those of the Syllabus of the Science and Art Department, South Kensington, and the treatment will be found to meet the requirements for the Examinations held by that Department.

In their wider scope the Manuals are intended to serve two somewhat different purposes :

1. They are designed, in the first place, for SELF-INSTRUCTION, and will present, in a form suitable for private study, the main subjects entering into an enlightened education; so that young persons in earnest about self-culture may be able to master them for themselves.

2. The other purpose of the Manuals is to serve as TEXT-BOOKS IN SCHOOLS. The mode of treatment naturally adopted in what is to be studied without a teacher, so far from being a drawback in a school-manual, will, it is believed, be a positive advantage. The subject is made, as far as possible, to unfold itself gradually, as if the pupil were discovering the principles himself, the chief function of the book being, to bring the materials before him, and to guide him by the shortest road to the discovery. This is now acknowledged to be the only profitable method of acquiring knowledge, whether as regards self-instruction or learning at school.

PREFACE.

It is now universally admitted that an acquaintance with the principal phenomena manifested by living beings, and more especially with the structure and mode of action of the different parts of the human body, is one of the most important branches of knowledge for men and women in all conditions of life. It is, therefore, no longer necessary to advocate the study of Physiology as a part of general education. In a very few years this subject will be efficiently taught in every public school throughout the country.

The object of the present text-book is to aid in this work. It professes to give such an account of the general mechanism and functions of the human body as ought to be known by every well-educated person. While aiming at brevity and clearness, the author has not attempted to avoid the use of technical terms, because such terms frequently express in a word a meaning which can only be conveyed in familiar language by circumlocution, and with the risk of vagueness. Many of the best of these terms have been handed down to us for generations, and they have become clear and definite symbols of thought. To attempt to teach a science without them, will simply result in giving the pupil vague and superficial notions, so that if he should be obliged again to study the subject with the view of entering one of the professions for which it forms a special branch of training, he will find that the work has, in a manner, to be done over again—indeed, that he has to learn the science anew. Many technical terms, however, have been explained, and their derivation given, in the Index.

The following pages may assist the teacher in two ways: (1) In preparing for the examination of the Science and Art Department; and (2) In teaching the subject to the more advanced boys and girls in the ordinary classes of the school, by whom it should be used as a text-book. The work has been specially planned to meet the requirements of the Science and Art Department. To aid

both in teaching and in learning, it will be observed that the subject has been broken up into numerous divisions and subdivisions, the headings of which have been so printed in diverse type as to catch the eye, and thus impress the memory; while at the end of the volume a number of questions are given, by which progress may from time to time be tested. The more abstruse topics have been printed in small type, so that they may be passed over by junior students, and used only by those who are more advanced. To assist the teacher also in the elucidation of any special subject, a list of works of reference is appended to the Index.

To teach physiology efficiently, it will be a great assistance to the teacher to have the following appliances:

(1.) *A human skeleton*, or the skeleton of any of the higher animals, such as a monkey, a dog, a cat, or a rabbit. Any of these may be obtained, by applying to any well-known bookseller or surgical-instrument maker.

(2.) *A good microscope*, capable of magnifying about 250 diameters. The one recommended by the author is that of Hartnack of Paris, sold by any instrument-maker at a cost of about £7. By means of this instrument, which ought to be provided by the authorities as part of the educational appliances of every school, a teacher might demonstrate most of the simpler tissues and fluids found in the body, and he would also be able to interest his pupils by shewing infusoria, the humbler forms of plant life, &c., many of which may be found in the water of every stagnant pool by the road-side.

(3.) *A set of diagrams*. These may be made by copying in Indian ink on a large scale, on cartridge paper, the wood-cuts in this work. To facilitate this method of illustration, a careful description will be found appended to each wood-cut.

(4.) *Dissected preparations*. These may readily be procured by dissecting a rabbit. Skin the front part of the body, and also a limb; clear off the loose tissue covering the muscles of the limb; separate the muscles from each other; expose the chief nerves and vessels in the limb; open the chest and abdomen, so as to be able to point out the appearance and position of the chief organs; and open the head, so as to expose the brain.

By such objective methods, after a little practice, the work of the teacher will become easy, and sound notions of anatomical structure and of physiological action will be taught.

JOHN G. M'KENDRICK.

GLASGOW UNIVERSITY, *November* 20, 1876.

CONTENTS.

I. GENERAL PHYSIOLOGY.

II. SPECIAL PHYSIOLOGY.

ANIMAL PHYSIOLOGY.

PHYSIOLOGY treats of the functions of living beings. It consists of two great divisions, Animal Physiology and Vegetable Physiology. As the latter belongs to the province of the botanist, we have nothing directly to do with it in this work, which will be devoted to a short exposition of the chief facts relating to the mechanism of the animal body, and more especially to that of the body of man. For the sake of convenience, the subject may be divided into General and Special Physiology.

I.—GENERAL PHYSIOLOGY.

This includes a description of (1) the anatomy or structure of the body, as it is revealed to us by dissection; (2) the chemical elements and compounds of which the body is composed; and (3) a general view of the body during that state of activity which we denominate life.

THE GENERAL ANATOMY OF THE BODY.

When the body of a man is looked at by the uninitiated, it appears to be so complex in structure as almost to baffle investigation, but, in the course of ages, men have succeeded by dissection in obtaining a tolerably accurate knowledge of the parts of which it is composed, so far as these can be seen by the naked eye. In more recent times, also, the microscope has been used for the examination of the minute structure of every organ and tissue; so that, while the department of microscopic anatomy is still

far from having been completely worked out, every year is adding to our knowledge. In describing the general anatomy of the body, therefore, it is convenient to divide it into (*a*) what may be seen with the naked eye; and (*b*) what can only be recognised with the microscope and with the aid of methods of investigation which have been invented during the last few years. The first division may be termed Systematic or Descriptive Anatomy; and the second, Histology (from *histos*, a web or tissue, and *logos*, a discourse) or Microscopical Anatomy.

SYSTEMATIC OR DESCRIPTIVE ANATOMY.

The body contains fluids and solids. The fluids are very abundant, existing not only in certain vessels or tubes fitted for their reception, but permeating the solid parts. Without these fluids the solid parts of the body would die. The solid parts consist chiefly of hard resisting parts termed the bones, and of softer structures forming muscle or flesh, and the various organs of the body, such as the brain, the lungs, or the heart.

THE LOCOMOTIVE APPARATUS.

This consists of two kinds of organs, the *bones* and the *muscles.* The *bones*, which are hard firm structures, form levers joined to each other by firm or movable *articulations* or *joints*, which often permit the bones to move on each other with great facility. The *muscles* constitute the chief part of what is usually called flesh, and they possess the property of contracting or shortening so as to move the bones with which they are connected by their extremities. The bones may be called the passive, and the muscles the active, organs of locomotion.

THE BONES.

1. THE SKELETON AS A WHOLE.—The whole of the bones in their natural position form the *skeleton*, which may be divided into the trunk and the limbs. The trunk consists of, first, the spine or vertebral column (fig. 1, 17, 19), a

flexible stalk formed of a number of distinct bones artic-

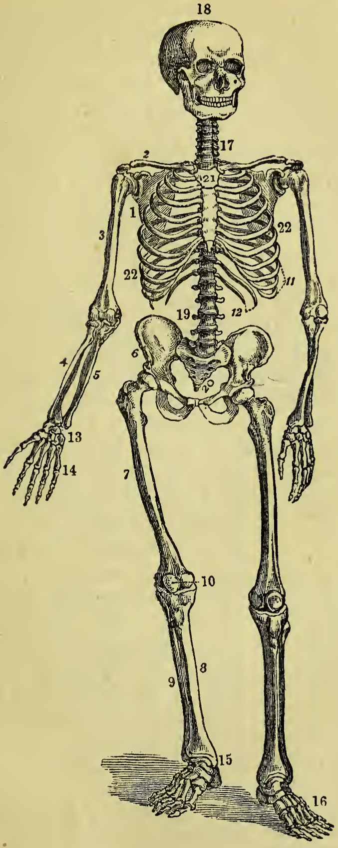

Fig. 1.—Human Skeleton viewed in front. For description see text.

ulated one below the other; second, the head, 18, con-

taining the brain and organs of sense, and consisting also of numerous bones; and, third, the *thorax*, or chest, 22, 22, composed of detached arches called the ribs, and which are connected in front, by *cartilage* or *gristle*, with a single bone, the *sternum*, 21. The thorax contains the principal organs of respiration and circulation.

The limbs, four in number, are termed *superior* and *inferior*. In man the inferior limbs support the trunk, while the anterior serve as organs of prehension; but in the lower mammalia, as in the horse or dog, all four support the trunk. The superior limbs are divided into the shoulder, 2; the arm, 3; the forearm, 4, 5; and the hand, 13, 14. The posterior limbs comprise the haunch or pelvis, 6; the thigh, 7; the leg, 8, 9; and the foot, 15, 16. In birds, the anterior or superior limbs constitute *wings*.

2. The Vertebral Column.—This consists of 24 free bones called *vertebræ*, and of two bones at the lower extremity, each composed of several vertebræ, termed the *sacrum* and *coccyx*, 20. Superiorly, it supports the skull; laterally, it has attached to it the ribs, through which it supports the weight of the upper limbs; and at its lower extremity it rests on the bones of the pelvis, 6, which transmit the weight of the body to the lower limbs. It also affords support and protection to the spinal marrow by inclosing it in a canal of bone. The bones of which it is composed are bound together by *ligaments* or bands, and by elastic discs of a fibrous and gristly substance called the *intervertebral* discs. There is thus secured great strength, combined with flexibility.

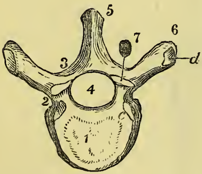

Fig. 2.—Dorsal Vertebra, viewed from above: 1, body; 2, pedicels; 3, laminæ; 4, ring; 5, spinous process; 6, transverse process; 7, articular process for next vertebra; *c*, facet for head of rib; *d*, facet for tubercle of rib.

3. General Characters of a Vertebra.—Each vertebra has more or less the form of a ring, and presents a body (fig. 2, 1), which is placed anteriorly; a ring, 4—containing the spinal

cord and its membranes—which is formed by the body, 1; the pedicels, 2; the laminæ, 3; and the spinous process, 5. Attached to the ring we find the transverse processes, 6, placed one on each side, and the articular processes, also one on each side, 7, two superior and two inferior, for connection with the adjoining vertebræ.

4. CHARACTERS PECULIAR TO GROUPS OF VERTEBRÆ.—The vertebræ are divided into three groups, *cervical*, in the neck; *dorsal*, in the back; and *lumbar*, in the loins. Of the first there are seven; of the second, twelve; and of the third, five. The first cervical vertebra, which supports the head, is called the *atlas* (fig. 3), and

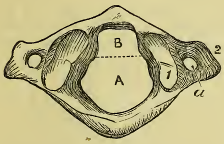

Fig. 3.—First Vertebra or Atlas: A, ring for spinal cord; B, ring for odontoid process of axis; dotted line indicates ligament; 1, articulation for occipital bone; 2, transverse process; *a*, canal for vertebral artery.

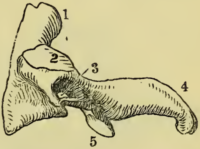

Fig. 4.—Second Vertebra or Axis: 1, odontoid process; 2, articulation for atlas; 3, canal for vertebral artery; 4, spinous process; 5, articulation for third cervical vertebra.

the second, the *axis*. The atlas has no body, and development would appear to shew that the process called the *odontoid process* of the axis (fig. 4, 1) is in reality the body of the atlas connected with the body of the axis. The general characters of a cervical vertebra are seen in fig. 5, the two chief points being the bifid spinous process, 3, and the canal in the transverse process for the vertebral artery, 5. The chief character by which a dorsal vertebra may be recognised is the presence on the body or transverse process of an articulating surface for the head or angle of the rib (see fig. 2, *c*, *d*). The lumbar vertebræ (fig. 6) have their bodies more massive than those of the dorsal, and the spinous processes are large, flat, and point directly backwards instead of downwards.

5. The SACRUM (fig. 1, 20, and fig. 7) is placed below the last lumbar vertebra, above the coccyx, and between

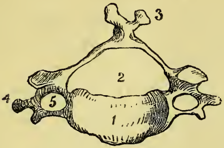

Fig. 5.—Cervical Vertebra: 1, body; 2, ring; 3, bifid spinous process; 4, transverse process; 5, canal for vertebral artery.

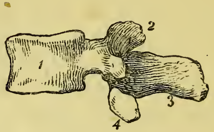

Fig. 6.—Lumbar Vertebra: 1, body; 2, transverse process; 3, spinous process; 4, articulation for next vertebra.

the pelvic bones (fig. 1, 6). It consists in early life of five vertebræ, which in the adult are united into one bone. The

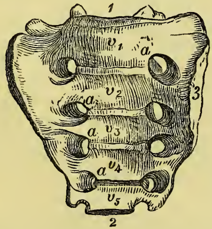

Fig. 7.—Front of Sacrum: 1, upper end; 2, lower end for coccyx; v_1—v_5, vertebræ coalesced; *a*, foramina for sacral nerves; 3, articulation of *os innominatum.*

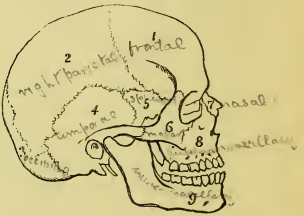

Fig. 8.—Lateral View of the Skull: 1, frontal; 2, right parietal; 3, occipital; 4, temporal; 5, wing of sphenoid; 6, malar; 7, nasal; 8, superior maxillary; 9, inferior maxillary.

coccyx, at the lower extremity of the vertebral column, consists of four rudimentary vertebræ, which diminish in size from above downwards.

The average length of the vertebral column is about 28 inches, and it presents four curves in its course, the convexity being forwards in the neck and loins, and backwards in the back and pelvis.

6. The SKULL is supported on the vertebral column, and is formed of a number of bones, all of which, with the excep-

tion of the lower jaw, are firmly fixed together by narrow surfaces termed *sutures*. It is divided by anatomists into two portions—the *cranium* and the *face*. The cranium protects the brain ; the face surrounds the nose and mouth, and contains several of the organs of sense. The cranium (fig. 8) is composed of eight bones—namely, the occipital, 3 ; the two parietal, 2 ; the frontal, 1 ; the two temporal, 4 ; the sphenoid, 5 ; and the ethmoid. The sphenoid forms part of the base of the skull (a little in front of 5, fig. 9), and the ethmoid is found immediately above and behind 7 in fig. 8, between the orbital plates of the frontal bone, and enters into the formation of the orbits and the nasal cavities. The *face* is composed of fourteen bones, of which twelve are in pairs, the two superior maxillary (fig. 8, 8, and fig. 9, 1, 1), the malar (fig. 8, 6), the nasal (fig. 8, 7), the palate (fig. 9, 2, 2), the lachrymal (a little to the left of 7 in the orbit) (fig. 8), and the inferior turbinated in the nose ; and two single, namely, the vomer, a bone forming a partition between the two nostrils (fig. 9, 3), and the inferior maxillary (fig. 8, 9).

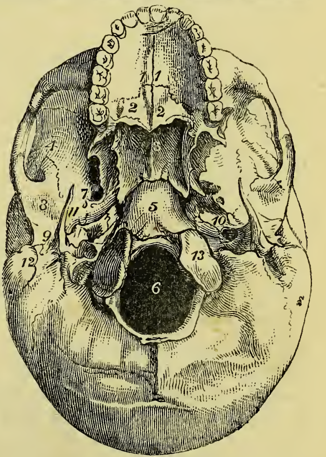

Fig. 9.—Base of Skull : 1, 1, superior maxillaries ; 2, 2, palate ; 3, vomer ; 4, wing of sphenoid ; 5, basilar process of occipital ; 6, foramen magnum ; 7, foramen ovale ; 8, temporal ; 9, 11, styloid process of temporal ; 12, mastoid process.

7. The CRANIAL CAVITY is seen on sawing off the roof of the skull. The walls consist of two layers of compact tissue, the *outer* and *inner tables*, and between these a cellular structure known as the *diploe*. The upper part of the cranial cavity forms an arch, and the lower is divided into three parts

having different levels, called the anterior, the middle, and the posterior fossæ, in which the anterior and middle lobes of the cerebrum and the cerebellum rest. The base is perforated by numerous openings for the passage of nerves and blood-vessels. The most notable of these openings is the *foramen magnum* (fig. 9, 6), for the passage of the spinal marrow and of certain blood-vessels.

8. VARIETIES OF SKULLS.—The different races of mankind present certain well-marked and characteristic peculiarities in the form of the skull. There are three typical forms—the *prognathous* (*pro*, forwards, and *gnathos*, a jaw), when the upper jaw slopes forwards, and the insertion of the teeth, instead of being perpendicular, is oblique (fig. 10), as seen in the negro of the Guinea

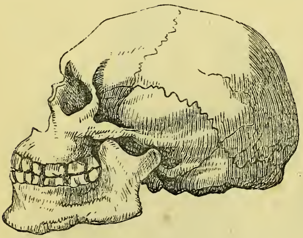

Fig. 10.—Prognathous Skull of a Native Australian.

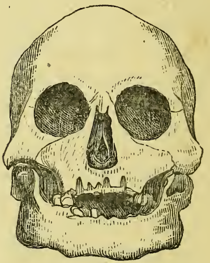

Fig. 11.—Pyramidal Skull of Mongolian Race.

coast and the native Australian; the pyramidal—sometimes termed *orthognathous* (*orthos*, straight) (fig. 11), characterised by the breadth and flatness of the face, which, with the narrowness of the forehead, gives a pyramidal form to the skull, as seen in the Esquimaux; and the oval or elliptical type (also orthognathous), presented by the natives of Western or Southern Europe (fig. 8). The length of the skull, which, to a certain degree, corresponds to the development of the lobes of the brain, has been taken as a basis of classification. Thus all mankind may be divided into two great classes—the *Dolicocephalæ*, or long-heads, and the *Brachycephalæ*, or short-heads. The latter, as a rule, possess greater cerebral development than the former. Each of these classes contains both prognathous and orthognathous skulls.

9. The THORAX, or chest, consists of the dorsal vertebræ, the *sternum* or breast-bone (fig. 12), the *ribs*, and the *cartilages* connecting these with the sternum, known as the costal cartilages. The sternum, C, is situated in the median line at the fore-part of the thorax, and is connected with the rest of the trunk by the costal cartilages of the seven highest pairs of ribs. The ribs are twelve in number on each side. They are long slender curved bones which extend forwards from the spine, some of them joining the breast-bone or sternum. The seven upper ribs, which join the sternum by cartilages, are termed the 'true' ribs; while the lower five, which do not join the sternum, are termed the 'false' ribs (see fig. 1, 12). Each rib has a double attachment to the backbone posteriorly; by its *head*, which unites with the body of the vertebræ (fig. 2, *c*), and by a rounded prominence, called the *tubercle*, with the transverse process of the vertebra (fig. 2, *d*). The costal cartilages are continuations of the ribs. They give elasticity to the framework of the thorax. In advanced life they become impregnated with earthy matter, partially lose their elasticity, and thus diminish the force and depth of respiration.

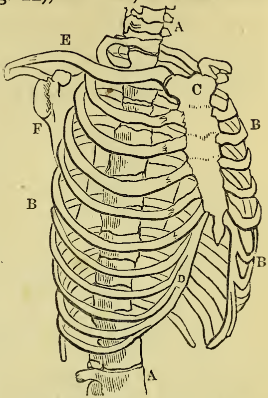

Fig. 12.—Antero-lateral View of Thorax: A, A, vertebræ; B, ribs; C, sternum; D, cartilages of ribs; E, clavicle; F, scapula.

10. THE BONES OF THE UPPER EXTREMITY.—The upper extremity consists of the shoulder, the arm, the fore-arm, and the hand. The bones of the shoulder are the scapula (fig. 1, 1), and clavicle or collar-bone (fig. 12, E); in the arm, is the humerus (fig. 1, 3); in the fore-arm, are the radius, 4, and ulna, 5; and in the hand, three groups of bones—the carpus, 13, metacarpus, 14, and digital phal-

anges. The *scapula* (fig. 13), placed on the upper and back part of the thorax, is attached directly to the trunk only by the clavicle, and from it the humerus is suspended. The *clavicle*, or collar-bone, is a long cylindrical bone placed on each side of the neck, and connecting the sternum with 2 (fig. 13), the acromion process of the scapula. The

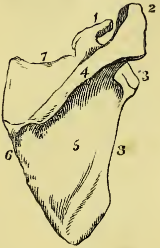

Fig. 13.—Back of Right Scapula: 1, coracoid, and 2, acromion process; 3, glenoid cavity for articulation with head of humerus; 4, spine; 5, body; 6, posterior, 7, superior, and 8, anterior borders.

Fig. 14.—Front View of Right Humerus: 1, shaft; 2, head; 3, bicipital groove; 4, external, and 5, internal tuberosity; 6, surface for ulna; 7, surface for radius.

humerus (fig. 14) is an imperfectly cylindrical bone, extending from the shoulder to the elbow-joint. In the figure it is seen as it is placed when the arm is dependent, and the palm turned forwards. It consists of a head, 2, which articulates with the scapula at 3 (fig. 13), of a shaft, 1, and of a lower end, 7, 6, which supports the radius and ulna. The two bones of the fore-arm are seen in fig. 15. They consist of the *radius*, A, which is the external of the two bones of the fore-arm, and the *ulna*, B, which is the internal. The radius articulates above with the humerus, and below with two of the bones of the carpus, or wrist. The ulna articulates with the humerus and the radius, but is not directly connected with the carpal bones, a thin, fibro-cartilaginous disc being interposed between its lower end and the cuneiform bone (fig. 16, *c*). When the arm and hand hang downwards, the palm being directed forwards, the position is called *supination;* but when in the same

position the back of the hand is directed forwards, the position is called *pronation*. These movements are effected by the rotation of the radius on the lower end of the humerus. The *carpus*, or wrist, consists of eight short bones, arranged in two rows. Enumerated from the radial or thumb side, they are (fig. 16), in the first row, the

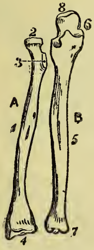

Fig. 15.—Front View of Right Radius (A) and Right Ulna (B): A—1, shaft; 2, round head; 3, articulation with ulna; 4, articulation with scaphoid and semilunar. B—5, shaft; 6, sigmoid cavity for humerus; 7, styloid process; 8, olecranon process at back of elbow.

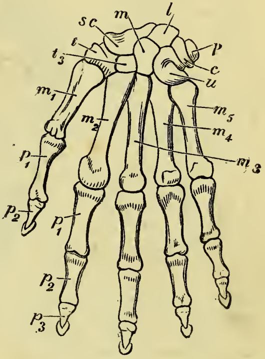

Fig. 16.—Posterior Aspect of Left Hand. For description, see text.

scaphoid, *sc*; the semilunar, *l*; the cuneiform, *c*; and pisiform, *p*; and in the second row, in the same order, the *trapezium*, *t*; the trapezoid, t_3; the os magnum, *m*; and the unciform, *u*. The *metacarpus*, forming the palm, consists of five shafted bones which support the fingers, m_1, m_2, m_3, m_4, and m_5. The *digital phalanges* are fourteen in number, three for each finger, except the thumb, which has only two. In each instance, the proximal phalanx, p_1, is longer than the second, p_2, and the second longer than the third, p_3.

11. The Bones of the Lower Extremity.—The lower limb is divided into the haunch or hip, the thigh, the leg, and the foot. The haunch-bone on each side, with the sacrum wedged in between, and bearing the coccyx at its lower extremity, forms the *pelvis*, which transmits the weight of

the body to the lower limb. It is usually called the *innominate* bone, or *os coxæ* (fig. **17**). The *pelvis*, or basin (fig. **18**), contains the urinary and generative organs and the lower end of the alimentary canal. Its upper opening is termed the *inlet*, and its lower the *outlet* of the pelvis. In the erect

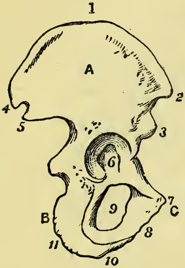

Fig. **17**.—Outer Aspect of Right Os Innominatum or Iliac Bone: A, ilium; B, ischium; C, pubis; 1, crest of ilium; 2, anterior superior spine; 3, anterior inferior spine; 4, posterior superior spine; 5, posterior inferior spine; 6, acetabulum; 7, symphysis pubis; 8, descending ramus of pubis; 9, obturator foramen; 10, ascending ramus of ischium; 11, tuberosity of ischium.

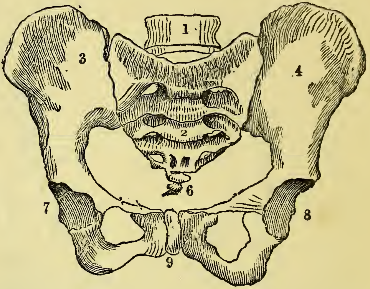

Fig. **18**.—Pelvis: 1, lower lumbar vertebræ; 2, sacrum; 3, right os innominatum; 4, left do.; 6, coccyx; 7, 8, acetabula; 9, symphysis pubis.

position (fig. **1**), the pelvis is so inclined that the plane of the brim forms an angle of from 60° to 65° with the horizontal. The line of pressure of the weight of the body on the sacrum is downwards and forwards towards the junction of the two innominate bones termed the symphysis pubis (fig. **18**, 9), and the pressure is communicated to the heads of the thigh-bones, which are lodged in deep depressions termed the acetabula (fig. **17**, 6; fig. **18**, 7; and fig. **1**). The form and size of the pelvis differ in the two sexes, as it is broader, more expanded, and shallower in the female than in the male.

The femur, or thigh-bone (fig. **19**), the largest bone of

the skeleton, articulates, 2, above with the acetabulum of the os innominatum (fig. 18, 7, 8). In the erect position it inclines inwards and slightly backwards, and it is divisible into a shaft, having at one end a head, 2, attached to it by a neck, 3, and bearing two rough prominences for the attachment of muscles, called respectively the great, 4, and the small, 5, *trochanters;* and at the other, or inferior extremity, a broad, irregularly shaped surface called the external, 6, and internal, 7, *condyles*, for articulation with the tibia. In the female, from the greater breadth of the pelvis, the thigh-bones converge more towards their lower extremity than in the male.

Fig. 19.—Front View of the Right Femur: 1, shaft; 2, head; 3, neck; 4, greater, and 5, lesser trochanters; 6, external, and 7, internal tuberosity; 8, articulation for tibia and patella.

The patella or knee-pan (fig. 1, 10) is situated in front of the knee-joint, and may be regarded as a mass of bone developed in the tendon or sinew belonging to the great muscle in front of the thigh by which the leg is extended on the thigh.

The bones of the leg are two in number, the inner termed the *tibia* or shin-bone (fig. 1, 8, and fig. 20, A), and the outer, the *fibula*, or clasp-bone (fig. 20, B). The tibia alone communicates the weight of the trunk to the foot. It articulates inferiorly with one of the bones of the ankle termed the *astragalus* (fig. 21, 1). The fibula is much more slender than the tibia.

The foot is divided into the *tarsus*, the *metatarsus*, and the *phalanges*. The tarsus consists of seven bones—namely (fig. 21), the os calcis, or heel-bone, 3; the astragalus, which receives the weight of the body from the leg, 1; the cuboid, so named from its shape, on the outer side of the foot, 8; the scaphoid or navicular bone, 4, and the three cuneiform or wedge-shaped bones intervening between the scaphoid and the metatarsals, 5, 6, 7; the metatarsal bones, 9, are five in number, and they bear the phalanges of the toes, 10, 11, 12, 13, 14.

The foot as a whole is admirably adapted for receiving the weight of the body, and for affording stability. It is arched from behind forwards, the posterior support of the

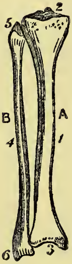

Fig. 20.—Front View of Right A, Tibia, and B, Fibula : A—1, shaft ; 2, articulation with femur ; 3, articulation with astragalus. B—4, shaft ; 5, head ; 6, lower end. Observe fork-shaped cavity at lower end for astragalus.

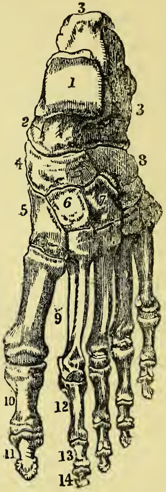

Fig. 21.—Upper View of Left Foot : 1, the astragalus, its upper articular surface ; 2, its anterior extremity, which articulates with 4, the scaphoid bone ; 3, the os calcis, or heel-bone ; 4, the scaphoid bone ; 5, the internal cuneiform bone ; 6, the middle cuneiform bone ; 7, the external cuneiform bone ; 8, the cuboid bone ; 9, the metatarsal bones of the first and second toes ; 10, 11, the first and second phalanges of the great toe ; 12, 13, 14, the first, second, and third phalanges of the second toe.

arch being formed by the heel, and the anterior by the balls of the toes—indeed, the arch may be regarded as having a single pier behind and a double in front.

12. Adaptation of the Skeleton of Man to the erect position.—The skull of man is nearly balanced on

the vertebral column, whereas in the lower animals it is suspended, as it were, from the extremity of the column, and is sustained by an elastic ligament (*ligamentum nuchæ*), which runs from the spinous processes of the vertebræ to a protuberance on the occipital bone. The body is balanced on one or both of the lower limbs, which can be extended in a straight line at the knee-joint. The foot of man alone possesses an arched instep, and the great toe is not intended for grasping, as in the monkeys, but for supporting weight and giving elasticity to the step. The great length of the femur enables the body to be balanced as in crouching, and the great breadth of the pelvis enables the equilibrium to be maintained even during considerable lateral movements. The spinal column, by becoming broader inferiorly, is fitted to sustain weight, and by means of its curvatures elasticity and strength are secured, while a wide range of movement is permitted. In man, the articular facet on the scapula for the head of the humerus looks outwards, so as to allow a free play of the upper extremity at the shoulder-joint. Mobility, lightness, and delicacy of movement are permitted by the structure of the upper limb, as contrasted with strength and firmness in the lower, as may be seen on comparing the shoulder, elbow, and wrist, with the hip, knee, and ankle.

THE JOINTS.

13. General Description.—A joint is the union of any two segments of the skeleton through the intervention of a structure or structures of a different nature. *Bone* forms the fundamental part of all joints; strong bands or *ligaments* hold the bones firmly together; and in joints in which there is free motion, we find the ends of the bones covered by *cartilage* or gristle, and the joint lined by a smooth membrane termed a *synovial* membrane. By anatomists, joints are divided into three classes—*synarthrosis*, where the parts are continuous and there is no synovial membrane between the bones, as seen in the construction of the skull; *amphiarthrosis*, where there is an intervening substance between the bones in the form of a disk or cushion of fibro-cartilaginous substance, allowing a certain degree of mobility, as in the articulations between the bodies of the vertebræ; and *diarthrosis*, where we find a complete joint having the ends of the bone covered with cartilage, the surface of

which is lubricated by the synovial fluid secreted from the delicate synovial membrane which lines the fibrous coverings and all parts of the articulating cavity except the cartilage. In diarthrosis the degree and nature of the movement are very various, but four varieties may be noted: (1) *Shifting joints*, where there is merely a gliding motion between the ends of the bones, as seen in the articulations between the bones of the carpus or tarsus. In these cases, the surfaces are plane, or one is slightly concave while the other is slightly convex; and the motion is limited in extent and direction by the ligaments of the joint, or by some projecting point of one of the bones. (2) *Ball and socket joints*, where one bone presents a cup-like depression, while the termination of the other assumes a hemispherical or more or less globular shape, as in the hip-joint. In such a joint, the ball is kept in apposition with the socket by means of what is termed a capsular ligament (fig. 22, 14, 14_1), which is an expansion of ligamentous structure, attached by its extremities around the margins of the articular surfaces composing the joint, and forming a complete investment of it, but not so tight as to restrict its movements too much. Fig. 22 shews the hip-joint, where in addition we find a strong round fibrous cord termed the *round ligament*, 12, passing from a depression in the head of the femur to the margin of the acetabulum or articular cavity on the *os innominatum*, 11. In such a joint the pressure of the air on the external surface assists in maintaining apposition, for when a hole is bored through the floor of the acetabulum so as to admit air into its cavity, the head of the thigh-bone at once falls away as far as the ligaments will allow it. (3) *Hinge joints*, in which the contiguous surfaces are marked by elevations and depressions, which exactly fit into each other, so as to restrict motion to one direction. The elbow and ankle joints are the best examples of this variety. The knee-joint is not a pure hinge joint, because it admits of a certain amount of rotation, when the leg is slightly bent at the knee. (4) *Rotatory joints*, which admit only of rotatory motion. A pivot

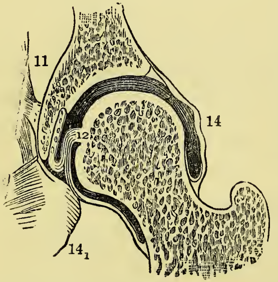

Fig. 22.—Section through the Left Hip-joint. For description see text.

and ring are the essential parts of this joint, the ring being generally composed partly of bone and partly of ligament. The best example of this articulation is that between the atlas (fig. 3, B) and the odontoid or tooth-like process of the axis (fig. 4, 1).

THE MUSCLES.

14. The active agents in locomotion are the muscles, which constitute the greater part of what we term flesh. On dissecting off the skin from one of the extremities, say the arm, we find underneath it a strong fibrous covering termed the *fascia*, which sends sheaths between the muscles, so that each muscle is completely surrounded by it. The fascia is usually divided into *superficial* and *deep*, the first being a layer of loose tissue placed immediately below the skin all over the body, and the latter is that stronger layer of fibrous tissue which lies close to the muscles, and invests them in the manner already indicated. On carefully removing the fascia, the muscles may be displayed, as seen in fig. 23, which represents the muscles of the human arm. If we examine a single muscle, as the biceps, *o*, it is found to be connected with the bones at its two extremities, and to present a fleshy mass between the two attachments, which are more tendinous or sinewy in character. Each muscle may be regarded as an organ having a special function to perform. When irritated during life,

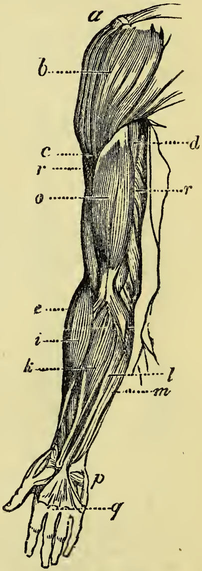

Fig. 23.—Human Arm: *abc*, deltoid muscle; *d*, coraco-brachialis muscle; *r*, *r*, triceps; *e*, *i*, extensors of wrist and long supinator of the hand; *km*, flexor of fingers and radial and ulnar sides of the wrist, and *l*, palm of the hand, or palmaris longus; *p*, palmaris brevis; *q*, palmar fascia; *o*, biceps.

it possesses the property of contracting or shortening itself, and consequently of bringing its two attachments nearer to each other. If there be a joint between the two attachments, the bones of this joint are moved upon each other in a definite direction, and thus locomotion is effected.

Space will not permit a detailed description of the various muscles found in the body, but they may be conveniently classified according to their mechanical action as follows: *Flexors*, or those which bend the limbs, such as the biceps (fig. 23, *o*); *extensors*, which straighten the limbs, such as the triceps, the fleshy mass on the back of the upper arm; *abductors*, and *adductors*, which produce angular movement to and from the median plane of the body, such as the muscles which enable us to move the thigh outwards and inwards from the hip; and *rotators*, which effect movement of a bone round its axis without any great change of situation. As an example of rotation, take those of pronation and supination already referred to (p. 16). In pronation (*pronus*, with the face downwards), we turn the palm of the hand downwards, as in picking up any substance from the table; in supination (*supinus*, with the face upwards), we turn the palm upwards, as for the purpose of receiving anything that may be placed in it. These movements are effected by certain muscles causing the radius, which bears the hand, to rotate round a longitudinal axis (see fig. 24). One of the three muscles (fig. 24, A) passes from a projecting process on the inner side of the humerus, at its lower end, to the outer edge of the middle of the radius. When it contracts, the radius rotates and rolls over in front of the ulna (as in fig. 24, 2), and it is called a *pronator* muscle. A second muscle (fig. 24, B) passes from a projecting process on the outer side of the humerus to the inner side of the radius near its upper part. It runs

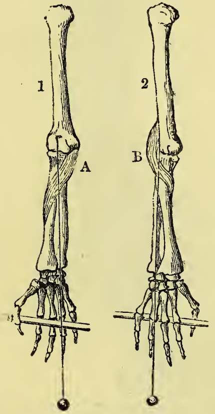

Fig. 24.—1, The Upper Limb, with the forearm and hand in the state of supination: A, pronator muscle. 2, The same in a state of pronation: B, the supinator muscle. In both figures, a plumb-line from the outer condyle of the humerus is found to traverse the lower end of the ulna and the ring-finger.

therefore in an opposite direction to the former muscle, and produces an opposite effect, rolling the radius and hand back into the position of supination. Hence it is called a *supinator*. The third muscle, the biceps (fig. 23, *o*), not only bends the elbow, but from the mode in which its tendon is inserted, it also rotates the radius so as to supinate the hand, as when we turn a screw, or draw a cork. Supination can only be performed to its full extent by man; monkeys can partially effect the movement, and in most of the lower animals the part corresponding anatomically to the hand is constantly in a state of pronation. Sometimes the combined action of various groups of muscles may take place, as when we swing the arm round and round in the shoulder-joint. This is termed *circumduction*, when the limb is made to describe a cone by rotation round an imaginary axis, the apex of the cone being in the joint.

ANIMAL MECHANICS.

15. Having described generally the bones, joints, and muscles, we now proceed to discuss briefly the mechanical arrangements met with in the body, or the physiology of movement.

Mechanical Arrangements of Muscles.

16. The great majority of the muscles of the body are attached to levers formed by the bones. Here the movable bone represents a lever of which the *fulcrum* is the articulation with the fixed bone, the *power* is employed at the point of insertion of the contracting muscle, and the *resistance* may be of various kinds according to the obstacles which tend to prevent displacement of the movable bone. In the body we find examples of levers of the first, of the second, and of the third order.

17. *Levers of the first order.*—Here we find the fulcrum between the power and the resistance. As an example, take the balancing of the head on the vertebral column: the fulcrum is the articulation between the occipital bone and the atlas; the resistance is the weight of that part of the head and face in front of the articulation, and the power is behind at the point of insertion of the muscles of the neck. The construction of the vertebral column, the balancing of the trunk on the pelvis, and of the leg on the

foot, represent levers of the same kind. Usually, in man, this kind of lever is for the purpose of *stability*, but we find it also in certain movements. For example, in extending the fore-arm upon the arm—the fulcrum is the elbow-joint, the power applied behind the articulation is the insertion of the triceps, and the resistance is the weight of the fore-arm in front of the articulation.

18. *Levers of the second order.*—Here the resistance is between the power and the fulcrum. In this lever the power-arm* is always longer than the resistance-arm. As the forces are inversely proportional to the length of the arms of the lever, a comparatively weak force will overcome considerable resistance, and consequently this lever is advantageous as regards expenditure of force. But it is disadvantageous as regards rapidity of movement, for the displacements of the two points of application are proportional to the lengths of the arms of the lever. For example, if the length of the power-arm = 10, and that of the resistance-arm = 1, a force of one pound would move a resistance of ten pounds, but the point of application of the power would be displaced ten feet, while that of the resistance would be displaced only one foot. This lever may be termed the lever of *power*. It is not common in the body. As an example, take the action of standing on tiptoe. Here the fulcrum is the contact of the toes with the ground; the power is at the insertion of the tendo Achillis, the strong ligament fixed into the *os calcis*, or heel-bone; and the resistance is the weight of the body transmitted to the articulation between the tibia and astragalus.

19. *Levers of the third order.*—The power is between the resistance and the fulcrum. In this lever, the resistance-arm is always longer than the power-arm, and while it is advantageous as regards swiftness, it is disadvantageous as regards expenditure of force. It may be termed the lever of *rapidity*. It is the one common in the

* The term *arms of the lever* is the distance which separates the fulcrum from the point of application of the power or of the resistance. The one may be called the *power-arm* and the other the *resistance-arm*.

movements of man. For instance, in the flexion of the fore-arm upon the arm—the fulcrum is the articulation at the elbow ; the power is at the insertion of the flexors (*brachialis anticus*, and *biceps*), and the resistance is the weight of the fore-arm. The power is usually applied in the body near the fulcrum, and the power-arm is thus much shorter than the resistance-arm, and hence only small weights can be moved, but with great speed. Thus the various movements of the body are rapidly performed, and the clumsy form of the limb which would have resulted had the power been applied near the resistance is obviated.

20. Simple movements such as are above described rarely take place. Usually the movements which one bone makes on another are not effected by one muscle, but by several, which may be regarded as associated together for that movement. Thus, in moving the arm, say from pronation to supination with a slight degree of flexion or extension, many muscles act.

Conditions of Equilibrium in the Body.

21. *Posture.*—In the natural erect posture, the human body becomes a rigid pillar without almost any muscular effort—the conditions being that the centre of gravity is supported by the base or surface between the points of contact of the soles of the feet with the floor. The centre of gravity of the head is in front of its point of support on the atlas, but the arrangements are such as to secure equilibrium chiefly by the action of the ligaments which bind the occipital bone to the atlas and axis. When the slight muscular effort required is withdrawn, as during sleep, the head droops forwards, and the chin rests on the chest. According to Weber, the centre of gravity of the trunk is situated in front of the tenth dorsal vertebra, and a plumb-line dropped from it passes behind a line connecting the two hip-joints, so that the trunk would tend to fall backwards were it not attached anteriorly by a firm ligament to the femur. The centre of gravity of the whole body lies immediately in front of the prominence of the sacrum (fig. 1), and a line suspended from it would pass a little in front of a line connecting the axes of both ankle-joints, so that the body has a tendency to fall forwards. This is prevented partly by the wedging of the astragali into the fork-like cavities formed by the lower ends of the tibia and fibula (fig. 20), and partly by the action of the muscles

forming the calf of the leg. As already pointed out (p. 20), the weight of the body falls upon an arch formed by the bones of the foot. In sitting, the trunk rests on the *tuber ischii* (see fig. 18), and tends to swing forwards and backwards on these. Thus there is an anterior and a posterior sitting posture.

22. *Locomotion.*—In walking, the pelvis is alternately supported by one of two legs. Starting, for example, with the right leg, the

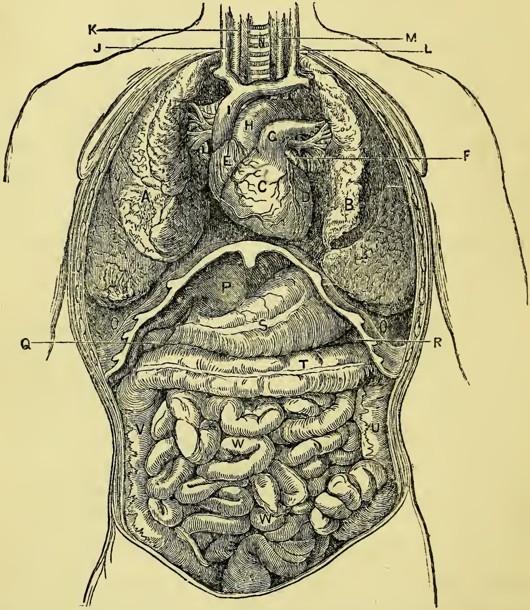

Fig. 25.—Contents of the Chest and Abdomen: O, diaphragm; C, heart; A, B, lungs; N, windpipe; P, liver; R, spleen; S, stomach; W, W, small intestine; T, U, V, large intestine.

body is inclined forwards, the right foot raised, the right leg advanced, and the foot put on the ground. Then the left heel is raised, but the toes of the left foot have not quitted the ground when the right foot has reached it, so that both feet are never off the ground at the same moment. The action of the muscles of the left

leg moves the body forwards, upwards, and to the right side. When the left foot has left the ground, the body is supported on the right leg, and the left leg swings forward like a pendulum to a position in advance of the right foot, constituting the second step. Rapidity of walking depends on the length of the step and the duration of the step, or the pendulum oscillation of the leg. The pendulum oscillation is the quicker the shorter the leg, hence the step of short-legged persons is quicker than that of long-legged ones. In running, the action is more like that of a series of jumps—that is to say, there are intervals in the step during which *both* feet are off the ground at once. At the commencement of the step in running, the active leg is strongly flexed, and then it is extended with a kind of sudden jerk.

THE INTERNAL ORGANS.

It will be most convenient to describe the general position, form, and size of these in connection with the physiology of each organ. They may be readily studied by the dissection of any common animal, such as a rabbit, or with the aid of models or plates, and their general position in the thorax and abdomen of the human body is seen in fig. 25.

HISTOLOGY, OR THE STRUCTURE OF THE TISSUES.

23. The ultimate elements of the tissues, in which delicate physiological processes occur, are of such small size that they can only be studied successfully with the aid of a good microscope, capable of magnifying from 20 to 350 diameters linear. They have been variously classified, but for convenience of description, we will group them under four heads—the molecular, the cellular, the fibrous, and the tubular elements of the tissues.

MOLECULAR ELEMENTS.

24. *General Description.*—When we examine under the microscope almost any of the fluids of the body, or a portion of any tissue teased out with needles in water, numerous minute particles are seen, varying in size from the $\frac{1}{100000}$th to the $\frac{1}{1000}$th of an inch in diameter. These are *molecules.* Many undoubtedly result from the disintegration of larger

bodies. Such molecules are termed *histolytic*, or molecules of disintegration. Others may be formed by a process somewhat comparable to precipitation in chemistry, as when a thin layer of oil is allowed to come into contact with a little pure albumen, such as white of egg; such molecules may be termed *histogenetic* or molecules of formation.

That molecules may combine under certain conditions to form larger bodies, and that thus a kind of structure may be formed, has been proved by Mr Rainey of St Thomas's Hospital, London, who found that, when carbonate of lime is allowed to separate from an aqueous solution, it assumes crystalline forms, but if the solution be viscous or glutinous, then oval or globular bodies are produced. These coalesce to form still larger bodies, similar to those seen in thin sections of the shells of crustacea (see fig. 26).

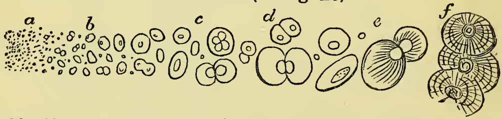

Fig. 26.—Forms of Carbonate of Lime deposited from a viscous solution on a slide of glass: *a*, molecular; *b*, small oval bodies, formed by coalescence of molecules; *c*, still larger bodies; *d*, still larger; *e*, bodies having lines radiating from centre; and *f*, large bodies having both radiating and concentrating lines, and precisely similar to those found in crab shell.

25. *Movements of Molecules.*—There are five modes of molecular movement:

(1.) The irregular to-and-fro movements known as the *Brunonian* movements, observed whenever molecules, whether dead or alive, are suspended in fluids.

(2.) Movements of molecules in the interior of cells. These may be seen in the interior of various vegetable cells (such as those of the *Chara*, *Vallisneria*, and *Tradescantia*), but they may also be seen in various animal cells, as, for example, in the salivary cell, with the aid of a powerful lens. These movements are sometimes definite in direction, and are accounted for so far by a circulation of the fluid in which they float; but in other cases, as in the salivary cell, they appear quite irregular, and have more of the character of Brunonian movements (fig. 32, *b*, p. 36).

(3.) The to-and-fro and zigzag movements of small particles of living matter called *Bacteria*, seen in putrid fluids.

(4.) The movements, often in a definite direction, of the molecules of the yolk of the egg after fecundation.

(5.) The movements of pigment molecules in certain cells of the skin of the frog, under the influence of light, as described by Mr Lister, and which account for the changes of colour in that animal with different intensities of light. When the animal is dark in colour, the molecules of dark pigment are diffused through the cell; but on exposure to light, or by section of the nerve supplying the part, or on the sudden death of the animal, the molecules crowd into the centre of the cell, and the skin becomes pale. Here we have an example of molecular movements under the influence of a physical agent, light, and also apparently affected by a vital agent, nerve force. A similar explanation probably accounts for the changes in colour of the chameleon, and of various fishes.

CELLULAR ELEMENTS.

26. *General Description of a Cell.*—A cell (fig. 27) is a microscopically small body, consisting of a soft substance termed protoplasm, in which there may be imbedded a body called a *nucleus*, *c*, in which there may be a still smaller body, *d*, known as the *nucleolus*. Sometimes the external boundary of the cell may become a hardened stratum, *a*, which is then called the *cell membrane* or *cell wall*. A cell is more than a molecule in a physiological sense; it is the smallest physiological apparatus, to a certain extent complete and independent. It is also a generally received doctrine that all tissues originate in cells. Not unfrequently several nuclei may be seen in the same cell or mass of protoplasm, as in fig. 30 (p. 33), *a* representing a cell or mass of protoplasm from the marrow of bone.

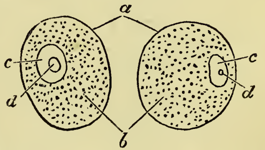

Fig. 27.—Two Cells of round or oval form: *a*, *a*, border of the cell; *b*, *b*, cell body; *c*, *c*, nuclei with nucleoli, *d*, *d*.

27. *Size of Cells.*—They vary in size from the $\frac{1}{3000}$th

(coloured blood-corpuscle) to the $\frac{1}{400}$th of an inch (the ovum).

28. *Form of Cells.*—This is extremely variable. The primary form is spherical or oval (fig. 27); but by compression they may become flattened (fig. 28); long and

Fig. 28. — Flattened scaly epithelium Cells from the lining membrane of the human mouth.

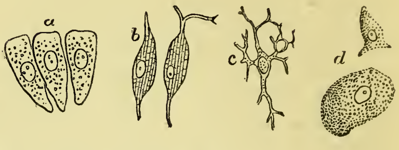

Fig. 29.—*a*, columnar epithelium; *b*, fusiform connective tissue cells; *c*, stellate cell from lymphatic gland; *d*, protoplasmic cells, with no cell-wall.

compressed, as in fig. 29, *a*; fusiform, *b*; and irregular or stellate, *c*.

29. *Nature of Protoplasm.*—This is a somewhat viscid matter sometimes having albuminous or fatty granules imbedded in it. It often receives the names of *bioplasm*, *cytoplasm*, and *sarcode*. It seems to be an unstable albuminous matter, insoluble in water, and coagulating at a high or low temperature or at death. It manifests properties which we term vital, because we cannot account for these properties by any known physical processes. It forms the chief part of young cells, but old cells may be filled with other matters, such as fat, pigment, or mineral substances. At an early stage, a cell (physiologically speaking) may consist of nothing more than a little mass of granular protoplasm, but it usually contains a nucleus (as in fig. 29, *d*).

30. *Chemical Constitution of Cells.*—Of this but little is known. The *cell substance*, as already stated, consists of a tough, viscid albuminous substance which coagulates at death or on being heated up to a certain point. This is about all we know at present regarding the chemistry of protoplasm. In many cells, protoplasm appears to be converted into other substances, such as ferments (as the pepsin found in the cells

of the glandular coat of the stomach), glycogen, a kind of animal starch found in the cells of the liver, and fats. The *nucleus* differs from the cell substance in resisting the action of weak acetic acid, and in having a remarkable affinity for most colouring matters ; and according to some authorities, it seems to be modified albuminous matter resembling elastic tissue (see p. 41). The *nucleolus*, from its refractive properties, is supposed to consist of fat.

31. *The phenomena of Vitality in Cells.*—These are : (1) absorption of matter ; (2) transformation of the same either into protoplasm, or some material formed by the cell, such as fat ; (3) excretion of certain materials which are to be got rid of so far as the cell is concerned ; (4) growth, or increase in size and development of parts by the imbibition of new matter ; (5) proliferation, or the development

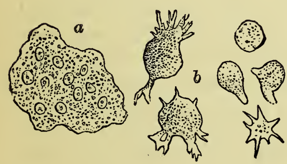

Fig. 30.—*a*, mass of nucleated protoplasm from marrow of bone ; *b*, lymph-cells, from inflamed eye, shewing amœboid processes ; *c*, various forms of colourless cells of the blood.

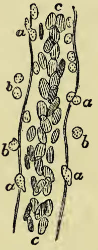

Fig. 31.—Blood-vessel in Mesentery of Frog during inflammation, shewing migration of colourless cells of the blood : *a*, cells passing through membranous wall of vessel ; *b*, cells which have passed through ; *c*, coloured cells in stream of blood.

of new cells from the old one ; and (6) in many the property of contractility. The latter property, which is one of the most remarkable phenomena of cell life recently discovered, may be observed in the colourless cells of the blood, and in the cells found in inflamed parts. On care-

fully watching these cells they are seen slowly to change their form by throwing out and retracting portions of their body. These movements, from their resemblance to those performed by the little amœba found in ditches, &c., are termed *amœboid.* It is a most interesting fact that there are many amœboid cells in the living body which wander from the blood-vessels throughout the tissues. It has recently been shewn that during inflammation, at all events in a transparent web or membrane, colourless blood cells pass from the blood through the walls of the vessels into the surrounding tissues, as seen in fig. 31, and become the cells of *matter* or *pus.* This phenomenon, which depends on the property of contractility in these minute cells, not only accounts for certain of the phenomena of inflammation, but also shews how it is possible that small particles of infecting substances may be taken up by amœboid cells and carried by the latter to distant localities in the body, to the danger or injury of the system.

32. *Conditions necessary for Cell Life.*—These are: (1) they must live in a nutritive fluid or *blastema*, from which they can select and attract the various substances necessary to enable them to carry on their functions; (2) they require a temperature not below zero nor above 145° F.—a low temperature retarding, while a high temperature favours, all growth; (3) they require room for expansion and an appropriate locality; and (4) the cell itself must be in a healthy condition—that is, the cell wall must not become thickened unduly by mineral matter; the cell substance or protoplasm must not be unduly loaded with albuminous, fatty, or mineral substances; and the nucleus in many cases must exist.

33. *Reproduction of Cells.*—Cells may multiply in one of four ways: (1) *endogenously*—that is, cells may arise within cells; (2) *exogenously*, the protoplasm may be extruded from the fully formed cell, and form cells outside of it; (3) *fissiparously*, the cell may divide by fission, each part then becoming an independent cell; and (4) *gemmiferously*, a bud may be given off from the cell-wall, which finally drops off and becomes an independent organism. Endogenous

formation may be seen in cartilage and in cancer cells; it is very doubtful if there are any true examples of exogenous formation—some authors denying its occurrence; fissiparous division may be noticed in the cells of the embryo, and sometimes in colourless corpuscles and pus cells; and gemmiferous formation or budding has been observed in the development of blood-corpuscles, and may be readily studied in the yeast plant (*Torula cerevisiæ*), when a drop of yeast is examined from time to time under the microscope.

34. *Varieties of Cells.*—Cells may be divided into: (1) normal isolated cells, floating in a fluid, such as lymph, chyle, and blood-corpuscles; (2) cells with a small amount of intercellular matter, such as epithelial cells; (3) cells imbedded in, and intimately connected with, other tissues, such as fat cells, pigment cells, and nerve cells; (4) cells on free membranes which secrete various fluids—secreting or gland cells; (5) cells which, during different periods in their earlier stage of development, present all the characters and functions of cells, but the tendency of which is to be transformed, or so arranged as to constitute a tissue—cells of transition—such as cartilage, colloid, connective tissue, and embryonic cells; and (6) cells found only in morbid conditions of the tissues, such as pus cells, cancer cells, and tubercle corpuscles.

Several of the different varieties of cells will be described when we treat of the fluid or tissue in which they are found, but there are certain kinds which must now be noted.

Epithelium and Endothelium.

35. *General Description of Epithelium.*—This is a tissue composed of cells in layers of greater or less thickness, which (1) covers the external and internal surfaces of the body, (2) lines the canals of exit, and (3) clothes numerous closed cavities, such as that between the wall of the chest and the lungs, termed the pleura. The cells found on free surfaces and in ducts are called *epithelial cells*, while those which line the shut cavities have recently been

termed *endothelial cells.* There are different varieties of epithelial cells, such as (1) flat, tesselated, or pavement epithelial cells from the lining membrane of the mouth (fig. 32, *a*); (2) globular or secreting cells from the ultimate structure of a gland (fig. 32, *b*); (3) columnar cells when they

Fig. 32.—Drop of Saliva, shewing *a*, pavement or squamous epithelium from mouth; and *b*, salivary cells.

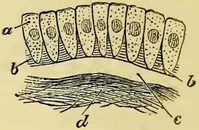

Fig. 33.—Simple coating of Columnar Epithelium on a Mucous Membrane: *a*, cells; *b*, intercellular matter; *c*, *d*, sub-cellular tissue.

adhere by their sides, as found on the mucous lining of the intestinal canal (fig. 33); and (4) ciliated cells, which may be either globular or columnar in shape, and are distinguished by having small processes or *cilia* at their free

Fig. 34.—Ciliated Epithelial Cells from the finer bronchial tubes.

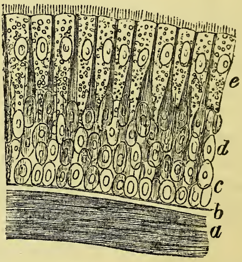

Fig. 35.—Row of Ciliated Epithelium Cells from the trachea of a man: *a*, fibrous tissue; *b*, basement membrane; *c*, *d*, cells in various stages of development; *e*, fully formed ciliated cells.

border (figs. 34 and 35). The function of epithelium is partly protective and partly for secreting certain matters from the blood.

36. *General Description of Endothelium.*—Lining the

interior of the closed cavities of the body, such as the chest and abdomen, we find a thin membrane usually called a *serous* membrane. This membrane consists essentially of a single layer of irregularly polygonal nucleated cells (resting on a thin structureless membrane called a *basement* membrane) placed edge to edge (fig. 36, *a*), called *endothelial* cells. The cavities of the heart and the whole of the blood-vessels are also lined by fusiform cells (fig. 36, *b*, *c*) of a similar kind. These cells are best displayed by staining the tissue with a dilute solution of nitrate of silver, and exposing it to light. The effect is so to blacken the edges of the cells as to make them quite apparent. *Serous* membranes secrete a thin watery fluid called *serum* or *serosity*, which lubricates the surface, and permits movement of adjacent parts on each other with little friction.

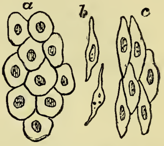

Fig. 36. — Endothelial Cells: *a*, from the pleura; *c*, from the lining membrane of a blood-vessel; *b*, similar cells isolated.

37. *Ciliary action.*—Ciliated epithelium is found in the air passages, such as the nose, pharynx or throat, trachea or windpipe, and bronchial tubes, in the cavities of the brain and central canal of the spinal marrow, in the middle ear, in the uterus, and in a few other localities. Each cell usually bears several cilia (figs. 34 and 35), and a nucleus. The beautiful undulating movement of cilia, sometimes similar to the appearance of a series of waves travelling along the surface of a field of wheat, at other times such as to convey the idea of running water, can scarcely be described; but it may be readily studied on the gills of the common mussel, or on the tentacles of many small sea-anemones, or other polypes. Ciliary motion persists for some time after the death of the animal, and in the case of cold-blooded animals it may continue for even ten or fifteen days after decapitation. The cause of ciliary movement is at present unknown. It does not depend directly on the nervous system, nor on a supply of blood, as it will continue in isolated parts for some time after these influences have

been removed. Usually it is asserted that it depends on an inherent property of contractility, but this statement is no real explanation of the phenomena. The action of cilia is undoubtedly to excite currents in the fluids in which they are immersed. In many infusoria, locomotion is entirely effected by the action of cilia. In the human body, they probably assist in the onward movement of mucus. Thus in the air passages, the action tends to propel mucus upwards towards the opening of the windpipe.

Pigment.

38. *General Description.*—This is found in the deeper layer of the epidermis or superficial layer of the skin, and also in the choroid or pigmentary coat of the eye (see EYE). It consists of cells filled with coloured matter placed side by side. There are two distinct forms of these cells: (1) the polygonal (fig. 37, *a*), and (2) the irregular or stellate, as seen in *b*. The colours of the various races of mankind depend on a greater or less amount of pigment in the skin. Such pigment cells are present in the skin of even the white races, and they are also found in the investing membrane of the spinal cord, in the membranous part of the internal ear, and in the interior of the nose. In the eye, the pigment obviously absorbs the redundant light; but its uses in the skin and in other parts are unknown. Individuals in whom pigment is wanting are called *Albinos.*

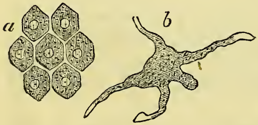

Fig. 37.—Pigment Cells: *a*, from choroid; *b*, from skin of frog.

Fat.

39. *General Description.*—This tissue consists of cells, termed *fat cells,* imbedded amongst fine fibres. The cells are round or oval (fig. 38, *a*, *b*), from the $\frac{1}{300}$th to the $\frac{1}{600}$th of an inch in diameter, and each consists of a delicate wall or envelope inclosing a drop of oily matter. When

young, they contain a nucleus, but this soon disappears from view. Frequently small stellate groups of crystals of fatty acids (probably margaric acid) may be seen in the interior (fig. 38, *b*). Fatty matter is usually called *adipose tissue*. It forms a considerable layer underneath the skin; covers various internal organs, such as the kidneys; is collected in the folds of the serous membranes of the abdominal cavity termed the mesentery and omentum; is common in the neighbourhood of joints, outside the synovial membrane; and it exists in large quantity in the bones, forming the chief part of the marrow. It is richly supplied with blood-vessels. The uses of fat are: (1) it acts mechanically as a light, soft, elastic packing for the cavities of the body, facilitating motion and diffusing pressure equally; (2) being a bad conductor of heat, it retains the warmth of the body—hence we find a thick layer of fat (*blubber*) underneath the skins of animals living in arctic regions; and (3) being composed chemically chiefly of carbon and hydrogen, it is consumed in respiration, and thus assists in maintaining animal heat (see ANIMAL HEAT). In a well-nourished human being, the amount of fat is said to be about $\frac{1}{20}$th of the weight of the body, but no doubt it fluctuates. Repose of body and mind, much sleep, and rich food favour the development of fat, and in some cases, especially in advanced life, the amount becomes so great as to constitute what we term *obesity*, which cannot be regarded as a healthy condition.

Fig. 38.—Fat Cells: *a*, imbedded amongst fine fibres; *b*, isolated, and containing small stellate deposits of crystals.

FIBROUS ELEMENTS.

40. A fibre is a solid elongated filament, microscopical in size, and a number of these together constitute a *fibrous tissue*, of which there are four varieties found in the human body. These are: (1) white fibrous tissue; (2) yellow elastic tissue; (3) involuntary or non-striated muscular fibre; and (4) voluntary or striated muscular fibre.

White Fibrous Tissue.

41. *General Description.*—This is frequently called *connective* tissue, because it binds the various tissues and organs together. It is found underneath and in the skin, between the muscles, in the blood-vessels, and other deep-seated parts, forming sheaths for these structures, and it enters more or less into the constitution of almost every organ. It is also continuous throughout the body. Hence dropsical effusions find their way throughout every part, and suppurations may spread from the spot where the matter or pus was first formed. White fibrous tissue consists of fine filaments (fig. 39, *a*) running in bundles which

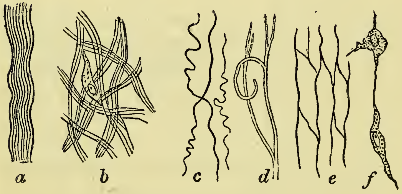

Fig. 39.—*a*, connective tissue in tendon; *b*, connective tissue from underneath the skin, shewing a connective tissue corpuscle; *c*, isolated white fibres; *d*, yellow elastic tissue; *e*, reticulated tissue of elastic fibres; *f*, connective tissue corpuscles, connected by a fine filament.

Fig. 40.—*a*, *b*, *c*, *d*, various forms of connective tissue corpuscles.

often cross each other so as to form spaces or areolæ. Hence it is sometimes termed *areolar tissue.* In the meshwork thus formed lie fat cells, blood-vessels, &c. In this kind of tissue we also meet with small irregularly formed nucleated cells (fig. 39, *f*, and fig. 40, *a*, *b*, *c*, *d*) termed *connective tissue corpuscles.* This kind of tissue swells up, and becomes transparent and gelatinous on the addition of a drop of weak acetic acid. *Tendon* or sinew is formed of parallel bundles of white fibrous tissue (see fig. 39, *a*).

Yellow Elastic Tissue.

42. *General Description.*—This is found in the ligaments which join the arches of adjacent vertebræ, in the coats of the larger blood-vessels, in the skin, and in many other structures. It may be conveniently studied in a bit of the *ligamentum nuchæ*, or ligament in the back of the neck for sustaining the heavy head of large quadrupeds. It consists of strong, coarse, yellow, elastic fibres (fig. **39**, *d*, *e*), which shew a tendency to split up and to curl up at the extremities. It is not affected by acetic acid. Its chief property is *elasticity*.

Muscular Tissue.

43. The two varieties of fibrous tissue above described possess only various physical properties, and act chiefly in a mechanical way in supporting or binding together, or in giving elasticity to various parts. Muscular tissue, in addition, possesses the property of contracting on the application of a stimulus. Of contractile fibrous tissue there are two varieties.

(1) *Involuntary or Non-striated Muscle.*

44. *General Description.*—This is so termed because its action is not subject to the will—that is, we cannot cause contraction in a part formed of it by willing to do so—and because it does not present the striated appearance characteristic of the other variety. It is found between the coats of the membranous viscera, such as the stomach, intestines, and bladder, in the walls of the air-tubes, ducts of glands, &c. It consists of flattened or ribbon-shaped bands (fig. **41**, *a*), which are composed of fusiform or spindle-shaped cells, *b*, sometimes shewing, on the addition of acetic acid, an elongated nucleus. It contracts slowly when stimulated.

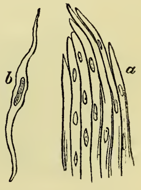

Fig. **41**.—*a*, portion of a band of involuntary muscular fibre; *b*, isolated cell, shewing nucleus.

(2) *Voluntary or Striated Muscle.*

45. *General Description.*—On examining one of the muscles of the extremities of any animal with the naked eye, we observe that it presents a fibrous appearance. The bundles are called *fasciculi* (fig. 42), inclosed in sheaths of white fibrous tissue. A fasciculus consists of a number of *fibres*, of varying size, each of which is inclosed in a structureless sheath or membrane called the

Fig. 42.—Muscular Fasciculus, shewing its division into fibres.

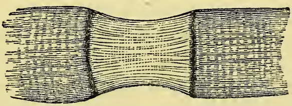

Fig. 43.—Muscular Fibre torn across, and shewing the delicate sarcolemma between.

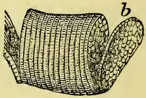

Fig. 44.—Muscular Fibre cleaving at the end transversely into disks.

sarcolemma (fig. 43). A fibre usually shews a tendency to cleave or split up in two directions, transversely into disks (fig. 44), and longitudinally into still smaller fibres, called

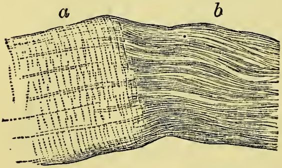

Fig. 45.—Portion of Muscular Fibre, *a*, shewing its connection with the tendon, *b*.

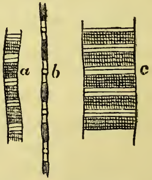

Fig. 46.—Portions of Muscular Fibre highly magnified, shewing sarcous elements: *a*, large fibril; *b*, ultimate fibril; *c*, small fibre.

fibrillæ (fig. 46). Each fibre shews transverse markings or *striæ* (hence the name), as seen in the various figures.

This striation is due to the fact that the ultimate fibril (fig. 46, *b*) is composed of small somewhat square-shaped bodies placed end to end, some of which, from the manner in which they are affected by light, appear dark and others light. These bodies are termed *sarcous elements*, by the union of which a fibril is formed. By studying the figures, the cause of the striated appearance will be at once understood. Recently it has been shewn that in the middle of the clear sarcous element there is a thin dark line. The length of the fibres is usually about that of the muscle in which they occur, and in the human body may vary from two lines to two feet. They are coarse in crustacea, reptiles, and fishes, and fine in birds and mammals, more especially in birds. They are attached at each end to tendinous substance (fig. 45), composed of white fibrous tissue, which in turn is inserted, or becomes continuous with the fibrous covering of bone.

46. *Chemical Constituents of Muscle.*—A living muscle in a state of repose contains, within the sarcolemma of each fibre, a semi-fluid substance called *muscle-plasma*, having an alkaline reaction. When this plasma is squeezed out of muscle it separates into two portions—a fluid termed *muscle serum*, and a solid clot which consists of an albuminous substance called *myosin*. The serum contains various albuminous matters; glycogen, a kind of animal starch; various matters previously formed from the decomposition of the muscle during action; salts, chiefly of potassium; water; and gases, chiefly carbonic acid. When a muscle dies, the semi-fluid matter solidifies, and the muscle stiffens. This is called *rigor mortis*. After a muscle has been stimulated to contract frequently, or kept in a state of contraction for some time, the plasma becomes *acid* instead of alkaline, from the formation of acid products of decomposition.

47. *Stimulation of Muscle.*—When a muscle is stimulated it contracts. This property of contracting on the application of a stimulus is called *irritability*, a property which has been shewn to depend on the inherent structure of the muscle itself, and not upon the nervous system, as was at one time supposed. The stimuli capable of causing a

muscle to contract are: (1) the *normal nervous* stimulus, transmitted along a nerve from a nervous centre; (2) *electrical stimuli*, as when it is irritated directly by an interrupted galvanic current, or by a Faradic current; (3) *chemical stimuli*, such as the application of a strong solution of common salt; (4) *thermal stimuli*, such as the momentary application of a hot wire; and (5) *mechanical stimuli*, such as pricking, pinching, &c.

48. *Work done by a Muscle.*—When a muscle contracts in its normal position, it does a certain amount of *work*, in the form of mechanical movement.

As work cannot be done without expenditure of material, the chemical composition of the muscle alters, so that the constituents which are soluble in water decrease in amount, while those soluble in alcohol increase. This fact clearly indicates that changes take place. When a muscle is stimulated, either directly, or indirectly by stimulating the nerve, it does not contract instantly, but there is a short period of inactivity, followed by the contraction. This period, called *the period of latent stimulation*, has been found to amount to about the $\frac{1}{100}$th part of a second. Physiologists have measured by carefully constructed instruments the work done by a muscle with different degrees of stimulation, and with different amounts of resistances to overcome. One general fact is that when a muscle contracts on stimulation, it may do an amount of work, say in lifting a weight, far in excess of the work represented by the stimulus. It thus appears that the muscle may be regarded as containing energy stored up, or in a *potential* state; while the function of the normal nerve stimulus is to set free this energy, or to make it active or *actual*.

49. *Various states of Muscular Contraction.*—When a muscle receives a single shock or stimulus of sufficient strength, say from a galvanic battery, it makes one contraction. If it receive a series of shocks, with sufficient time intervening between the shocks, it contracts and returns to its former size with each shock; but each shock after a certain time weakens the muscle, so that it by-and-by will not contract on the application of the stimulus. This state of exhaustion of the muscle is called *muscular fatigue.* If a muscle receive a number of shocks in quick succession, so rapid that it has no time to relax completely between the shocks, it becomes stiff and rigid. The rigid condition thus produced is called *Tetanus.* It has been recently shewn that the normal contraction of a muscle is also

an effect of this kind. When a muscle, say the biceps in the front of the arm, contracts in obedience to a voluntary effort, it does not do so by one shock or current of nervous energy being transmitted to it along the nerves from the brain, but by the action of many. One nervous shock after another follows with great rapidity, and in consequence the muscle gathers itself up or contracts.

50. *Thermic Phenomena of Muscle.*—Muscles are hotter during contraction than during a state of rest. This has been ascertained experimentally, and the heat thus produced may be regarded not only as an expression of the chemical changes occurring in the muscle, but also as the appearance, in the form of heat, of a portion of the energy stored up in the muscle.

51. *Electrical Phenomena of Living Muscle.*—When a muscle, say the small muscle from the back of the leg of a frog, is cut so that the transverse section may be adjusted to one of the terminals of a galvanometer, and the longitudinal surface to the other, and the circuit of the galvanometer is opened, a movement of the needle at once indicates the presence of an electrical current. It may be shewn that this current flows through the galvanometer from the longitudinal surface to the transverse section—that is, the former is positive, and the latter negative. If in these circumstances the muscle be caused to contract, the needle swings back towards zero—that is, during muscular contraction, the current observed during rest becomes less. This diminution during contraction is termed the *negative variation of the muscle current.*

TUBULAR ELEMENTS.

52. By a tube is meant a microscopical filament composed of a wall and contents. When viewed under a high power, magnifying 250 diameters linear, with transmitted light, it is distinguished from a fibre by one or two thin lines on each side, the inner line gradually shading off into a bright clear space in the centre. Optically, a transparent fibre shews a broad dark band on each side of a narrow clear centre. In the body, we find four varieties of tubes, which will be described in their proper place in discussing the functions with which they are connected. They are—(1) air-tubes, in the air-passages and lungs; (2) blood-tubes, in the various kinds of blood-vessels; (3) dental tubes, forming part of the structure of a tooth; and (4) nerve-tubes, usually termed nerve-fibres, the conducting filaments of the nervous system.

There are certain tissues which cannot be conveniently classified under any of the four divisions of molecular, cellular, fibrous, and tubular elements. These are (1) cartilage, or gristle; and (2) bone. Of these we shall now give a brief account.

Cartilage.

53. *General Description.*—When in mass, cartilage is opaque, pearly or bluish white, and translucent when cut in thin slices. It is highly and perfectly elastic. There are two varieties, temporary and permanent. *Temporary* cartilage is seen in the embryo, where the skeleton is cartilaginous, but in due time the cartilage is replaced by bone. *Permanent* cartilage continues as cartilage throughout life. It is seen covering the ends of bones, and entering into the formation of joints, forming an elastic pad which breaks the force of concussions; it forms the cartilages of the ribs (fig. 12, D), and part of the external ear, the nose, the eyelids, the larynx, the windpipe, and the tube leading from the back of the throat to the middle ear, known as the Eustachian tube. When a thin piece of cartilage is examined microscopically, it is seen to consist of a mass of finely granular material known as *matrix*, in which lie imbedded nucleated cells, called *cartilage* cells. When cartilage is boiled for a considerable time, it yields a substance termed *chondrin.*

54. *Varieties of Cartilage.*—These are: (1) *hyaline*, in which the matrix is clear and transparent, or finely molecular, giving it the appearance of ground-glass (fig. 47, *a*); (2) *white fibro-cartilage*, in which the matrix has become fibrous, the fibres having the characters of those of white fibrous tissue, as seen in the disks between the vertebræ; and (3) *yellow fibro-cartilage*, in which the fibres

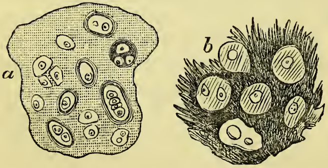

Fig. 47.—Cartilage: *a*, hyaline, shewing cells lying in a slightly granular matrix; *b*, yellow fibrous, shewing cells lying in meshwork of coarse fibres.

resemble those of yellow fibrous tissue, resisting the action of acetic acid, and forming a dense matting or felt, in the meshes of which the cells lie (fig. 47, *b*). Yellow fibro-cartilage is sparingly distributed in the body, being found only in certain of the cartilages of the ear and of the larynx.

Bone.

55. *General Description.*—Bones are divided by anatomists into the *long* or cylindrical, the *flat* or tabular, and the *short* or irregular. The femur is an example of the first (fig. 19, p. 19), the parietal of the second (fig. 8, 2, p. 12), and the astragalus of the third (fig. 21, 1, p. 20). When any

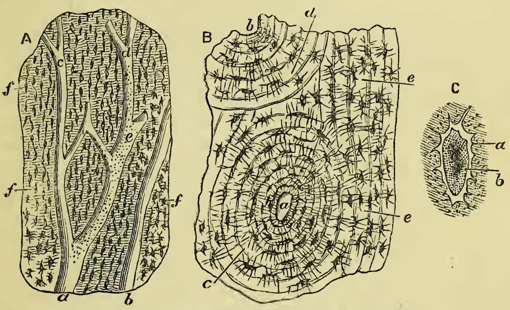

Fig. 48.—Bone: A, longitudinal section, shewing ramifications of Haversian canals, *a*, *c*, *d*, *e*, and *f*, *f*, lacunæ and canaliculi. B, transverse section, shewing one complete Haversian system, *a*; part of another, *b*; and an outer lamina, *e*, *e*; *a* is the transverse section of a Haversian canal. C, bone corpuscle in lacuna, highly magnified; *b*, bone corpuscle, a mass of protoplasm; *a*, space between it and bony matter.

of these bones is sawn across, two kinds of bony tissue are seen—a hard compact part next the surfaces of the bone, and a spongy or *cancellated* part formed of bands and plates in the centre. In the centre of a long bone there is a canal termed the *medullary canal*, filled with a soft, reddish, pulpy substance called the marrow. The marrow, when examined microscopically, shews fat cells, large nucleated cells (fig. 30, *a*), and blood-corpuscles. In the cancellated

tissue, both in the heads of the long bones and in the flat and irregular bones, there is a pulpy matter of a similar character. To examine the microscopic structure of a piece of hard bone, two methods may be followed : (1) by sawing off thin sections of dried bone, polishing and grinding them into extremely thin slabs on a lapidary's wheel, or on a hone ; or (2) by steeping the bone in dilute hydrochloric acid for a few weeks, so as to dissolve out the earthy matter, and leave only the cartilaginous basis, which is so soft as to cut readily into thin sections with a sharp knife. On examining a *longitudinal* section of bone made by the first method, a series of canals are seen ramifying through the bone (fig. 48, A), called *Haversian canals*, for carrying blood-vessels, &c., and by the sides of these canals numerous little dark oblong bodies, from which delicate dark lines pass. On examining a *transverse* section of bone (fig. 48, B), a transverse section of the Haversian canal or canals is seen, *a*, *b*, surrounded by laminæ of bone, in which are imbedded oval dark bones termed *lacunæ*, from which radiate outwards and inwards numerous very delicate canals known as *canaliculi*. In dead bone, the lacunæ and canaliculi are empty, or filled with bone-dust, but during life each lacuna is occupied by a little mass of protoplasm called a *bone corpuscle* (fig. 48, C), and by the canaliculi a complete circulation is established throughout the bone. These arrangements are evidently intended for the nutrition of the bone. The nutritious matter transudes from the blood-vessels in the Haversian canals, passes through the system of canaliculi which communicate with these to the first row of lacunæ, and so on throughout not only the entire *Haversian system*, as it is termed, which surrounds the canal, *a*, but through adjacent systems such as *b*.

56. *Growth of a Bone.*—Every bone is formed either in membrane or cartilage, and the process is called *ossification*. It is a process too obscure and difficult to be treated of in this elementary work, but there are certain practical facts regarding the growth of a bone which may be briefly described. In the early embryonic state, a long bone, say the femur (fig. 49), is entirely cartilaginous ; but at a certain definite period a deposit of earthy matter takes place in the

shaft, which gradually extends towards each extremity, so that about the eighth month of fœtal life, the shaft is completely ossified, A, but both ends are cartilaginous. At birth a second deposit of earthy matter (termed an *ossific centre*) has taken place in the lower end, B. After birth the bone grows in length and thickness. At the age of one year, a second ossific centre makes its appearance in the head of the bone, C. We have now three ossified portions, the shaft, the lower extremity, and the upper extremity. Between the ossified shaft and the partially ossified extremities, the bone is still cartilaginous, and it is here that growth in length chiefly takes place. A study of fig. 49 will shew the subsequent steps by which the bone becomes entirely ossified. The ossified portions separate from the shaft are termed *epiphyses.* After a bone has become completely ossified, it ceases to grow in length, but it may increase in thickness by the development of new bony material on the outside, beneath the fibrous covering of the bone termed the *periosteum.* Each bone is richly supplied with blood by the vessels of the periosteum, and by a special nutrient vessel which usually penetrates the bone. These facts shew (1) that bone is not a dead inert mass, as many may suppose, but that it is a living growing tissue, especially in early life; and (2) that in early life, before the long bones of the lower extremities have completely ossified by union of the epiphyses with the shaft, there is danger of bending the bones at the cartilaginous portions and in the shaft by allowing the child to walk at too early a period.

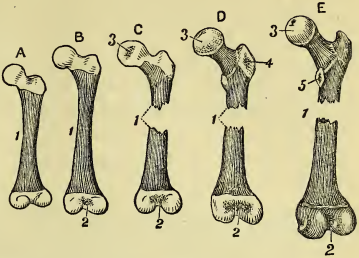

Fig. 49.—Ossification of the Femur: A, femur of a fœtus about eight months; the body is osseous; both ends are cartilaginous. B, femur of a child at birth, shewing a nucleus of earthy matter, 2, in the lower end. C, femur of a child of about a year old, shewing a nucleus in the articular head, 3. D, femur of the fifth or sixth year, where ossification has extended from the shaft into the nucleus in the head, and a nucleus has appeared in the great trochanter, 4. E, femur of about the age of puberty, shewing more complete ossification, and a nucleus in lesser trochanter, 5.—Quain.

57. *Chemical Constitution of Bone.*—Bone consists of an earthy

and of an animal part. The animal part is a soft flexible substance obtained as above mentioned by steeping a bone in diluted hydrochloric acid. On boiling this, it yields gelatine. The earthy part, got by burning bones, consists largely of tribasic phosphate of lime, carbonate of lime, fluoride of calcium, phosphate of magnesia, and chloride of sodium. In old age, the bones become brittle from the large amount of earthy salts they then contain.

CHEMICAL CONSTITUTION OF THE BODY, AND THE CHEMICAL ACTIONS OCCURRING IN IT.

In connection with this department of physiology, we shall briefly discuss (1) the chief elementary constituents of the human body; (2) the chief compounds which have been isolated by the chemist; and (3) the chief chemical changes which occur in the living organism.

ELEMENTARY CONSTITUENTS.

58. The principal elementary constituents are carbon, oxygen, hydrogen, and nitrogen. Those next in importance, or at all events in frequency, are sulphur, phosphorus, chlorine, sodium, potassium, calcium, and iron. The first four are met with in all the fluids and solids of the body; sulphur in albuminous matters, blood, and in most secretions; phosphorus in blood, nervous matter, bone, the teeth, and in most liquids; fluorine in bone and the teeth; chlorine everywhere; sodium everywhere; potassium in the muscles, coloured blood-corpuscles, nervous matter, and secretions; calcium in bone, teeth, and fluids; magnesium usually accompanies calcium; iron in the colouring matter of the blood, bile, urine, &c. The rarer bodies are silicon, lithium, manganese, copper, and lead.

COMPOUNDS.

Of these there are two classes—*inorganic*, such as water or phosphate of lime, and *organic*, such as albumen or urea.

Inorganic Compounds.

59. These may be divided into water, inorganic acids, inorganic bases, and salts.

Water forms about two-thirds of the weight of the body, so that a body weighing about 165 lbs. will contain about 110 lbs. of water. Certain tissues contain very little water, such as the substance of tooth, bone, &c.; whereas others, such as brain-matter and muscles, contain a great amount.

Inorganic Acids.—These are hydrochloric, hydrofluoric, phosphoric, sulphuric, and silicic. None of these occur in the free state (except, perhaps, the first in the juice of the stomach), but are combined with sodium, potassium, calcium, &c.

Inorganic Bases.—These are soda, potash, ammonia, lime, and magnesia. None occur free, but are combined with acids to form salts.

Salts.—These are numerous, but the chief are chloride of sodium, chloride of potassium, chloride of ammonium, fluoride of calcium, phosphates of sodium and potassium, phosphate of calcium, phosphate of magnesium, and sulphates of sodium and potassium. The most important as regards amount is the chloride of sodium, of which about 3086 grains, or over six ounces, exist in an average human body.

Organic Compounds.

60. Such may be divided primarily into those containing nitrogen, or *nitrogenous*, and those not containing nitrogen, or the *non-nitrogenous*. The nitrogenous include albuminates, albuminoids, and albuminous derivatives. The non-nitrogenous include certain organic acids, animal starch and the sugars, the fats, and the alcohols. The albuminates comprise such substances as common *albumen* (familiar as white of egg), found in blood, chyle, lymph, &c.; *casein*, found in milk, constituting cheese; and *myosin*, or muscle-clot, already referred to (p. 43). The albuminoids are so termed because, while they have properties peculiar to each, they have certain general properties resembling those of the albuminates. The chief are *gelatin*, obtained

by boiling skin, sinew, &c.; *chondrin*, got by boiling cartilage; and *elastin*, made by the prolonged boiling of elastic tissue. The albuminous derivatives probably do not form a constituent part of any tissue, but as they are made in the economy by those chemical dissolutions of more complex substances on which vital activity would seem largely to depend, they are always found either in the solids or in the excretions. The chief are *urea* and *uric acid*, two substances in the urine which will be afterwards described; *leucin*, *tyrosin*, *cystin*, and *taurin*, found in bile; *creatin* and *creatinin*, existing in muscle-juice; and *lecithin* and *cerebrin*, found in nervous matter. These will be subsequently referred to in treating of the juices in which they occur.

61. The non-nitrogenous substances comprise four different kinds of bodies—namely:

Organic Acids.—Certain organic acids, which are usually united with bases forming salts. The chief of these are *carbonic*, *formic*, *acetic*, *propionic*, *butyric*, *palmitic*, *stearic*, *oleic*, *lactic*, *oxalic*, *succinic*, &c.

Animal Starch and Sugar.—Animal starch or *glycogen* has the same chemical formula as common starch. It is found in the liver and muscles, and also in the tissues of the embryo. Of sugars there are three varieties to be met with in the body: *glycose*, or grape-sugar, in the alimentary canal; *inosite*, or muscle-sugar, found chiefly in the heart; and *lactose*, or sugar of milk, found in milk.

Fats.—Chemically considered, a fat is a triatomic alcohol, glycerin, in which one, two, or three of the atoms of hydrogen are replaced by the radicle of a fatty acid. Of such compounds in the body there are three—*stearin*, *palmitin*, and *olein*, which are found in all fatty matter. About four or five pounds of fatty matter may be found in a body of average size and weight.

Alcohols.—According to chemists, an alcohol is a substance constructed on the type of one or more molecules of water in which one or more of the atoms of hydrogen are replaced by a radicle. For example, common alcohol is on the type of one molecule of water in which one of the

hydrogen atoms is replaced by the monatomic radicle, ethyl. In the body only two compounds are known which physiological chemists refer to this group—*glycerin*, which is the basis of all the fats, and *cholestrin*, which exists in bile, and in a solid state forms the chief constituent of gall-stones.

CHEMICAL CHANGES IN THE LIVING ORGANISM.

62. A little reflection will at once indicate how difficult it is to attempt to investigate the chemical changes occurring in a living tissue or in a living being. True it is we may collect and analyse every excretion, we may examine the air before and after breathing, and we may analyse the food, and give such food as we think may vary the conditions of the inquiry; but these procedures throw little light on the chemical compositions and decompositions in the tissues and organs which we know do take place. Still, without direct evidence perhaps, but supported by all the known facts, and justified by all analogies, we can say that in the body the chemical changes may be classified as follows: oxidations, decompositions, reductions, syntheses, and fermentations.

63. *Oxidations in the Body.*—These constitute the great majority of the chemical changes occurring in the body. By oxidation is meant the union with oxygen of one or more constituents of a complex substance, so as, in most cases, to form one less complex. Oxidations may go on step by step, each gradation being simpler than the one immediately preceding it. Thus the terminal products of the oxidation of albuminous substances are urea, water, and carbonic acid, and of the fats, water and carbonic acid. By artificial processes of oxidation the chemist has succeeded in producing many simpler compounds, and thus he has imitated the processes going on in the body. From albuminous matter he has formed leucin, tyrosin, glycocoll; and from uric acid, urea, oxalic, and carbonic acids, &c. The agent in processes of oxidation is, of course, oxygen introduced by respiration. These processes seem to be essential to the production of all vital actions.

64. *Decompositions in the Body.*—By decomposition is meant the splitting up of a substance into two or more components, the combined weight of which represents exactly that of the compound. Thus one of the acid substances found in the bile, taurocholic acid, splits up into taurin, and cholic acid, and the sum of the atomic weights of the latter two is exactly equal to that of the former. Some substances lose one or more molecules of water, and thus become chemically changed. For example, creatin and creatinin, compounds found in muscle-juice, differ only by a molecule of water. Such a process of abstracting water is called *dehydration.* Recently it has been conjectured that some processes occurring in the body are what the chemist terms *dissociation*, by which is meant a decomposition occurring at a certain temperature and pressure or tension, in which the substances which have been separated will re-unite to form the primitive compound when the former conditions as to temperature and pressure are re-established.

65. *Reductions.*—By the term reduction is meant the removal of oxygen from a complex body. It rarely happens apparently in the animal body.

66. *Syntheses.*—The formation of compound bodies by a process of building up or synthesis is less understood than processes of decomposition. Sometimes this process simply consists of one of hydration—that is, a compound unites with water to form a more complex body. Thus creatin combines with a molecule of water and becomes creatinin. Chemists have synthetically produced many of the substances formed naturally in the body, such as urea, hippuric acid, taurin, sarcosin, creatin, oxalic acid, succinic acid, acetic acid, &c., but little is known as to the steps by which these bodies are formed in the body.

67. *Fermentations.*—Many examples of fermentive changes occur in the body. The *ferments* are produced by living cells in certain glands. Thus we have ptyalin, the ferment of the saliva, formed in the salivary glands; pepsin, the ferment formed in the gastric glands of the stomach, &c. Their chemical constitution resembles that of albuminous matters, but they contain no sulphur. The following are

examples of fermentive processes: (1) The transformation of starch into dextrin and into glycose, produced by the action of ptyalin and pancreatin, and also under the influence of all albuminous matters, especially in the act of decomposition; (2) the transformation of fats into fatty acids and glycerin, accomplished by the pancreatic ferment; and (3) the transformation of albuminates into peptones, or soluble modifications of albumen, as happens under the action of the pepsin of the gastric juice and of the pancreatic ferment. For the accomplishment of fermentation, certain conditions of moisture and temperature are required. These conditions exist in the animal body, so that the chemical transformations of food during the process of digestion are due to the action of soluble ferments. Probably also, similar changes occur in the more obscure processes of nutrition, and in the actions of certain glands, such, for example, as the liver, where apparently a fermentive substance is formed which converts glycogen or animal starch into sugar.

THE ANIMAL BODY IN ACTION.

Many of the phenomena of the body in action have been already alluded to, such as the properties of the various tissues and the chemical changes in the organism. The remainder will be described under Special Physiology, after which we will consider the views held by physiologists regarding Life or Vitality and Death.

II.—SPECIAL PHYSIOLOGY.

68. The functions of the human body may be conveniently classified into three great divisions: (1) *Nutrition*, or the nourishment of every part of the body, so as to enable each part to perform its special function; (2) *Innervation*, or the actions performed by the nerves, spinal cord, brain, and organs of sense; and (3) *Reproduction*, or the perpetuation of the species by offspring.

THE FUNCTION OF NUTRITION.

69. This function is a complex process. To keep up the integrity and vigour of the body, food must be procured, chewed or masticated, mixed with saliva, swallowed, digested in the stomach, the nutritious material absorbed

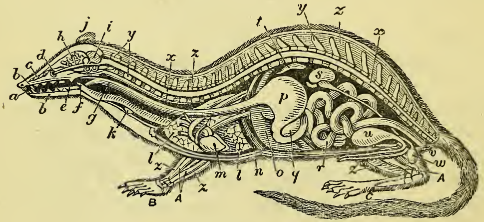

Fig. 50.—Diagram of a Vertebrate Animal (Owen): *a*, mouth; *b*, *b*, teeth; *c*, olfactory nerve; *d*, optic nerve; *e*, palate; *f*, epiglottis; *g*, œsophagus, or gullet; *h*, cerebrum, or great brain; *i*, cerebellum, or lesser brain; *j*, external ear; *k*, trachea, or windpipe; *l*, lung; *m*, heart; *n*, diaphragm; *o*, liver; *p*, stomach; *q*, pancreas; *r*, small intestine; *s*, kidney; *t*, spleen; *u*, bladder; *v*, anus; *w*, testicle; *x*, *x*, spinal cord; *y*, processes of vertebræ; *z*, muscle. A, A, bones of legs; B, foot; C, hind-leg.

by special organs in the bowels, called villi, and from them carried to various glands, where it is elaborated into blood. The blood is then conveyed through the body, giving up to the tissues what they require for nourishment, and

carrying away materials resulting from their decay. Thus rendered impure, the blood must have the noxious materials removed. For this purpose, several organs, such as the lungs, the liver, the skin, the kidneys, and the lower bowel, are set apart. Thus the blood is constantly replenished with nutritious matters, and constantly being purified, so as to fit it for supplying each individual particle or cell of the body with exactly the material it requires. Bone requires earthy salts, muscle requires albumen, the nervous system requires fat, and so on.

The general arrangement of the nutritive organs is seen in fig. **50**, representing an ideal longitudinal section of a vertebrate animal ; fig. **25**, p. 28, should also be studied.

The process of nutrition is complex only in the higher animals. In the amœba (fig. **51**), a little animal which is nothing more than a mass of jelly-like living material, containing a nucleus, *a*, and a nucleolus, *b*, we find no trace of organs, and nutrition is carried on by any part of the body. A little fragment of nutritious matter is surrounded by the protoplasm of the body of the animal, *c*, and by it is also converted into protoplasm. But as we ascend in the scale of animal life, one organ after another is added, such as a digestive sac, glands for secretions to act on the food, a special fluid—the blood, an organ and vessels for circulating this fluid ; and so on, till we come to the higher animals, where we find a complex system in operation.

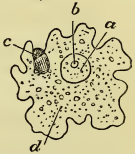

Fig. **51**.—Amœba : *a*, nucleus ; *b*, nucleolus ; *c*, morsel of nutritious matter being absorbed ; *d*, protoplasmic body.

70. Nutrition may be divided conveniently into a number of stages, of which there are twelve ; but before discussing these, we must endeavour to understand the nature of the food or aliment by which matter and energy are introduced into the body.

FOOD OR ALIMENT.

71. *Necessity for Food.*—A living being is always in a state of change. His skin gives off water, either in the form of sweat or as invisible vapours ; his kidneys act

similarly, the water in both cases containing salts and other matters in solution ; and his lungs are always exhaling, not only watery vapour, but the gas known as carbonic acid, as may be readily shewn by breathing into lime-water, which soon assumes a milky appearance, in consequence of the formation of carbonate of lime. Moreover, the body, which has an almost constant temperature of about 98·4° F., is always giving off heat, so that if a man were surrounded by ice, part of the ice would be melted, and the amount of heat might be estimated by the amount of water produced. The production of heat indicates chemical changes in the body, accompanied by waste of material. In addition, there is a constant expenditure of energy in carrying on the work of the body, or in doing the daily outside work of life. If this condition of things were to go on indefinitely, the weight of the body would gradually diminish. To retain the body in an efficient state both as regards matter and energy, it must be supplied with *atmospheric air*, *water*, and *food*. We have placed them in the order of their importance.

72. *Physiological Importance of the Air*.—The atmosphere consists of a mechanical mixture of 4 measures of nitrogen and 1 measure of oxygen. In 100 volumes of air, there are 20·81 of oxygen and 79·19 of nitrogen. By weight, in 100 parts, there are 23·01 of oxygen and 76·99 of nitrogen. In addition, the air always contains a small amount of carbonic acid (about 4 parts in 10,000 parts), a variable but minute trace of ammonia, traces of nitric acid, and frequently in towns a small amount of sulphurous acid and sulphuretted hydrogen. Finally, it contains variable quantities of aqueous vapour. The constituent of greatest importance in the economy of the body is oxygen. Without this gas, life cannot be prolonged for more than a few minutes. Consequently, there are special arrangements for introducing it into the body. This constitutes part of the process of respiration.

73. *Physiological Importance of Water*.—When we recollect that water is present in every tissue of the body, and especially in those tissues which are of the greatest

importance to life, such as brain or muscle, we see at once the importance of a due supply of this fluid. The presence of water is a condition of all vital activity. It is the solvent by which substances are brought into close contact with each other, and it is the medium in which all those molecular processes occur on which life depends. It is remarkable too that it is in a constant state of transition in the body, and as it is continually being given off, it must be replenished. Hence all animals introduce into the body water, either as such, or combined with the food.

74. *Classifications of Food.*—Various classifications of the food of man have been proposed; but the following is simple and practical: The *aqueous;* the *albuminous;* the *fatty*, *oily*, or *oleaginous;* the *saccharine;* the *gelatinous;* and the *saline* groups. All our daily food is referable to one or more of these classes. The *aqueous* group includes not only water, but all fluids (except oils) used as drink, and it must be recollected that all our so-called solid foods contain a large percentage of water. The *albuminous* group (often termed the protein) is typified by the white of egg, and includes the gluten of flour, and the chief constituents of flesh and cheese. These substances contain the four elements, carbon, hydrogen, oxygen, and nitrogen, and also a little sulphur or phosphorus, or both. The albuminous foods chiefly nourish the muscles, but they contribute, along with fat or oil, to almost every tissue. The *fatty* group includes all animal and vegetable fats or oils. They are composed of carbon (ranging from sixty to eighty per cent.), hydrogen, and a little oxygen. The *saccharine* (often termed the starchy or amyloid) group contains all the varieties of sugar, starch, dextrin, and gum; like the preceding group, they are composed solely of carbon, hydrogen, and oxygen. The starches and sugars belong to the group termed by chemists *carbohydrates*, because they contain carbon or charcoal, and oxygen and hydrogen, in the proportions necessary to form water. Sugars and starches contain enough oxygen in their own composition for this purpose, but fats require to be oxidised chiefly at the expense of oxygen

from without. This group contributes chiefly to the fatty tissue of the body. The *gelatinous* group is represented by cow-heel, isinglass, and such-like substances, yielding jellies and soups that stiffen on cooling; while the *saline* group includes mineral matters, especially common salt, and phosphates of the alkalies, and of lime, &c. The saline or mineral matters form bone, tooth, &c., and they are found in variable proportions in almost every fluid and solid in the body. It must be remembered, however, that a *mixture* of all of these constituents of food is essential to the formation of a nutritious diet, and, moreover, that there must always be a certain amount of *sapidity* or *flavour* in the food. We should turn with disgust from a mess consisting of these constituents, even in proper proportions, if it were not properly cooked. The best example of a natural food is milk. It contains water, albumen in the form of casein or cheese, fat in the form of butter, sugar, and various salts. Hence it is nature's food for all young animals of the mammalian group.

75. *Conditions determining the quantity of Food.*—These are: (1) the amount of oxygen in the atmosphere and the temperature; (2) the amount of mental and bodily exertion; and (3) the activity of growth. Exercise and exposure to cold sharpen the appetite, and thus lead to more food being taken. It is also well known that dwellers in the arctic regions not only eat a great deal of food, but of that kind which, by oxidation by the oxygen of the air, is heat-producing—namely, oleaginous matter. On the other hand, the inhabitants of the tropics eat sparingly, and chiefly of products rich in carbo-hydrates (that is, substances composed of carbon, hydrogen, and oxygen, with enough of the latter to oxidise the two former), such as starch, sugar, &c. In a temperate clime, something between the two extremes is found to be most conducive to health.

76. *Food and Work.*—It is evident that the amount of food must have some direct relation to the work done by the individual. Hard work means expenditure of matter and energy, and these must be supplied by food. The following table shews the quantities, in ounces avoirdupois, of

the different materials of dry food required under different circumstances :

Nature of the Diet.	Nitrogenous matter.	Fat.	Carbo-hydrates.	Salts.	Total.
Bare subsistence diet.......	2·33	0·84	11·69	...	14·86
Adult in full health, with moderate exercise.........	4·215	1·397	18·960	0·714	25·286
Active labourer, not over-worked......................	5·41	2·41	17·92	0·68	26·42
Hard-working labourer, navvy........................	5·64	2·34	20·41	0·68	29·07

Add to each of these from 60 to 80 ounces of water, taken either alone or as part of the food in a succulent or cooked state. Thus it would appear that in ordinary life, and with a fair amount of labour to perform, a healthy adult requires about 28 or 30 ounces of dry nutritious food per diem, along with about 70 ounces of water.

77. *Different kinds of Food.*—The nutritious value of different articles of diet depends (1) on their digestibility; and (2) on the amount they contain of the proximate constituents which are required for nourishing the body. There are great differences in the percentage composition of food, as may be seen on studying the following table :

TABLE SHEWING THE PERCENTAGE COMPOSITION OF VARIOUS ARTICLES OF FOOD (*Pavy*).

Nature of Food.	Water.	Albumen.	Starch.	Sugar.	Fats.	Salts.
Bread..................	37	8·1	47·4	3·6	1·6	2·3
Wheat flour..........	15	10·8	66·3	4·2	2·0	1·7
Oatmeal...............	15	12·6	58·4	5·4	5·6	3·0
Rice.....................	13	6·3	79·1	0·4	0·7	0·5
Potatoes...............	75	2·1	18·8	3·2	0·2	0·7
Peas.....................	15	23·0	55·4	2·0	2·1	2·5
New milk.............	86	4·1	...	5·2	3·9	0·8
Cheese.................	36·6	33·5	...	...	24·3	5·4
Beef.....................	51	14·8	...	...	29·8	4·4
Pork	39	9·8	...	...	48·9	2·3
Poultry.................	74	21·0	...	...	3·8	1·2
White fish............	78	18·1	...	...	2·9	1·0
Egg......................	74	14·0	...	...	10·5	1·5

A glance at the preceding table will also shew that the habit of combining different articles of diet, such as bread and butter, beef and potatoes, chicken and ham, &c. is physiologically correct. It also shews that oatmeal porridge and milk make a highly nutritious diet.

We shall now describe the steps in the process of nutrition.

MASTICATION.

78. Mastication is effected in the cavity of the mouth by means of the teeth, which fit into sockets in the upper and lower jaw-bones (fig. 8, p. 12 ; also fig. 53, p. 63). The upper jaw is immovable, or only movable with the entire head ; but the lower jaw, with its teeth, is capable of moving upwards, downwards, backwards, forwards, and laterally, by means of the powerful muscles of mastication. It is by the varied movements of the lower teeth against the upper, through the action of these muscles, that food is broken down or masticated. The *tongue* also, moved by its muscles, gathers together the food from below the dental arches, and crushes

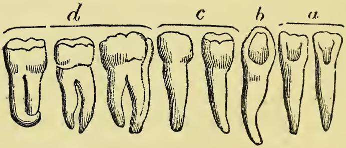

Fig. 52.—The separate Human Teeth as they occur in the half-jaw of the adult : *a*, incisors ; *b*, canine ; *c*, bicuspids ; *d*, molars.

it against the palate. In the adult there are 32 teeth, 16 in each jaw, and 8 on each side. There are from before backwards, beginning in the middle line of the jaw, 2 incisors or cutting teeth on each side ; 1 canine or eye-tooth, for seizing ; 2 premolars or bicuspids, for tearing ; and 3 molars or grinders, for crushing and breaking up the food (fig. 52). The body and greater bulk of each tooth consists of a substance called *dentine* (fig. 53, *b*), composed of branching tubes ; the top or crown is covered by a cap of *enamel*, a very hard substance, made of small hexag-

onal prisms (fig. 53, *a*, and fig. 54); and the fang or root is protected by a layer of a material resembling bone, called *crusta petrosa* or cement (fig. 53, *c*). In the centre of each

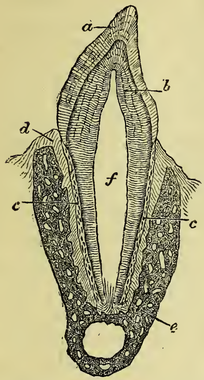

Fig. 53.—Vertical Section through a Tooth lodged in its socket: *a*, enamel; *b*, dentine; *c*, crusta petrosa or cement; *d*, lining of the cavity in the gum; *e*, bony socket in gum; *f*, pulp-cavity.

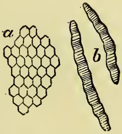

Fig. 54.—*a*, surface of enamel prisms; *b*, two prisms isolated.

tooth there is a cavity containing a pulpy matter, in which are nerves and blood-vessels (fig. 53, *f*).

79. *Nerves of the Tongue.*—These are: (1) the *Hypoglossal*, the motor nerve of the tongue; (2) the lingual branch of the *fifth*, conferring sensibility to touch to the anterior two-thirds of the tongue; (3) the *glosso-pharyngeal*, conferring sensibility both as to touch and taste to the posterior third; and (4) the *chorda tympani*, a branch of the facial, which confers the sense of taste on the tip of the tongue.

INSALIVATION.

80. Insalivation is effected by the admixture of the secretions of three pairs of salivary glands (the parotids, the sub-maxillaries, and the sub-linguals), and of the mucus secreted by numerous small glands beneath the lining of

the cheeks, gums, and tongue, called *buccal* glands, with the triturated food. The salivary glands belong to the class of what are called *racemose* glands, consisting of numerous ducts which divide and subdivide until they become extremely small. At the extremities of the ducts there are a series of little pouches or follicles, lined by the cells which secrete from the blood materials which they manufacture into saliva. Recently it has been shewn that certain of the filaments of the nerves actually terminate in the cells, or send fine filaments amongst them (fig. 55). The common *saliva* formed by the combined secretion of these various secreting organs, is a colourless, slightly turbid, viscid, inodorous, and tasteless fluid. In the normal state, its reaction is alkaline. Saliva does not contain more than five or six parts of solid constituents to 995 or 994 parts of water. The daily quantity of saliva secreted by an adult man is estimated at about 48 ounces, but the activity of the salivary glands is dependent upon various influences and conditions. Thus, movement of the lower jaw, as in masticating, speaking, or singing, increases the secretion —acrid and aromatic substances and hard dry food also increase it. It is also under the influence of mental emotions and desires, through the nervous system, for the sight of a feast or tempting dish may make one's 'mouth water.'

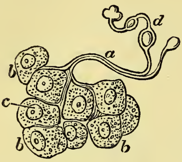

Fig. 55.—Nerves terminating in a cluster of Cells in a salivary gland: *a*, nerve; *b*, *b*, *b*, cells; *c*, nucleus; *d*, small swellings or nerve tubes.

The uses of the saliva in reference to digestion are partly mechanical and partly chemical. The chemical use of the saliva is, by the fermentive action of its active principle, *ptyalin*, to convert the starchy portions of the food into grape-sugar, and thus to promote its absorption. It also moistens the mouth, and thus assists in speech and swallowing. The public speaker cannot articulate when his mouth becomes dry, and we cannot swallow a perfectly dry powder.

81. *Nerves of the Salivary Glands.*—These have been studied chiefly in the sub-maxillary gland. It receives nerve fibres from three sources—namely: (1) from the facial; (2) from the sub-maxillary ganglion; and (3) from the cervical sympathetic. When the chorda is irritated, the arteries of the gland dilate, the veins pulsate, and the secretion becomes copious and watery. On irritating the sympathetic, the arteries contract, the circulation becomes slower, the veins are filled with black blood, and the secretion becomes tenacious and scanty. The filaments of the sympathetic would appear to be *vaso-motor*, that is, governing the vessels; while those of the chorda influence the secretion directly. The filaments of the lingual branch of the fifth, distributed to the mouth, carry impressions, say of contact or sapidity, to the centre in the brain; from thence the influence travels along the chorda to the gland, and secretion is the result. The sub-maxillary ganglion acts as an intermediate centre from which the impression may be reflected without going to the brain. This mechanism serves as an illustration of the relation of the nervous system to secretion.

DEGLUTITION.

82. Deglutition is the act by which the food is transferred from the mouth to the stomach. The mouth leads into a cavity called the *pharynx*. Between it and the mouth is the pendulous or soft *palate*, which is a movable muscular partition that separates the two cavities during mastication. As soon, however, as the latter act is accomplished, and the bolus is pressed backwards by the tongue, the soft palate is drawn upwards and backwards, so as to prevent the food passing into the nose. The opening of the windpipe is closed by a lid called the *epiglottis*. The bolus or pellet of food having arrived near the œsophagus or gullet (which is continuous inferiorly and posteriorly with the pharynx), is driven into it by the action of certain muscles, which almost surround the pharynx, and are termed its constrictor muscles. All voluntary action ceases as soon as the food is pressed backwards by the tongue into the pharynx. It is impossible to recall the pellet, and it is necessarily carried on (without even our cognisance) into the stomach. This involuntary mechanism is called a

reflex action. All reflex actions require a stimulus to call the parts into action. The stimulus in this case is the contact of the food with the back of the tongue and throat. It will be found on experiment that the reader cannot perform the action of swallowing if nothing, not even saliva, is in his mouth.

83. *The Nervous Arrangements in Deglutition.*—This is an excellent example of *a reflex action*, the nature of which may be here shortly described. The conditions of every reflex action are: (1) a *centre* usually in some part of the central nervous system; (2) an afferent or *sensory* nerve, to carry impressions towards the centre (fig. 57, A, arrow); and (3) an efferent or *motor* nerve, to carry impressions outwards from the centre. Suppose in fig. 57 an irritation is

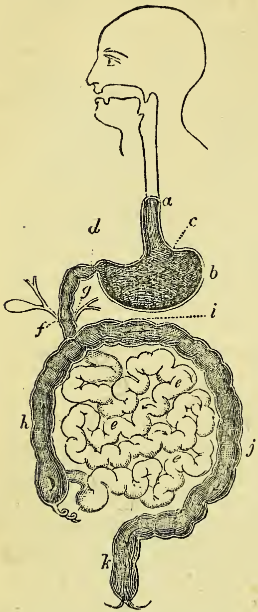

Fig. 56.—Diagram of the Human Alimentary Canal: *a*, œsophagus; *b*, stomach; *c*, cardiac orifice; *d*, pylorus; *e*, small intestine; *f*, biliary duct; *g*, pancreatic duct; *h*, ascending colon; *i*, transverse colon; *j*, descending colon; *k*, rectum.

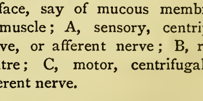

Fig. 57.—Diagram shewing the mechanism of a simple reflex action: 1, surface, say of mucous membrane. 2, muscle; A, sensory, centripetal nerve, or afferent nerve; B, reflex centre; C, motor, centrifugal, or efferent nerve.

applied at 1, an impression is carried by A to B, and from B *reflected* or transmitted along C to 2, a muscle, and the consequence is a muscular contraction. This is an automatic mechanism beyond the control of the will, and is called an *excito-motor* act. Usually the conditions are more complex. Thus there may be numerous sensory and motor nerves, and even more than one centre, involved, as in

deglutition. In the latter, the *excitor* impressions are carried to the *medulla oblongata* chiefly through the glosso-pharyngeal, and also along branches of the fifth, distributed to the back of the throat, and along the superior laryngeal branches of the pneumogastric from the pharynx. The *motor* influence passes along the pharyngeal branches of the pneumogastric, along branches of the hypoglossal to the muscles of the tongue, along the motor filaments of the recurrent laryngeals, through some branches of the fifth, along branches of the facial, and probably along some branches of the cervical plexus.

84. The food is carried down the œsophagus or gullet to the stomach by a peculiar vermicular contraction of its muscular fibres, well seen when a horse is drinking water. This kind of movement is called a *peristaltic* action.

DIGESTION IN THE STOMACH.

85. *General Description of Alimentary Canal.*—The whole of the alimentary canal below the diaphragm, or muscular partition which separates the cavity of the chest from that of the abdomen or belly (fig. 25, O, p. 28), possesses the following points in common, in relation to structure. The stomach, the small intestine, and the large intestine, are all lined by mucous membrane, have a muscular coat of involuntary muscular fibres, consisting of two sets of distinct fibres —namely, circular fibres which surround the tube or viscus after the manner of a series of rings, and longitudinal fibres running in the same direction as the intestine itself—and are invested with a smooth, glossy, serous membrane, which, while it retains the viscera in their proper position, also permits their necessary movement with a minimum of friction.

86. *General Description of Stomach.*—The human stomach is an elongated curved pouch (fig. 56, *c*), lying immediately below the diaphragm. It is very dilatable and contractile, and its function is to retain the food until it is duly acted upon and dissolved by the gastric juice, which is secreted by glands lying in its inner coat, and then to transmit it, in a semi-fluid state, into the first part of the small intestine, called the duodenum. Its average capacity is about five pints.

87. *Description of Mucous Membrane of Stomach.*—The mucous membrane, or lining coat of the stomach, is thick and soft, and lies in irregular folds, in consequence of the contraction of the muscular coat, unless when the organ is distended with food. On opening the stomach, and stretching it so as to remove the appearance of folds, we perceive numerous very shallow pits or depressions (fig. 58, A). The rest of the thickness is chiefly made up of minute tubes (fig. 58, B), running vertically towards the surface of the stomach, and secreting the gastric juice from the blood in the capillaries or minute blood-vessels which abound in the mucous membrane. These tubes are lined half-way down with epithelial cells (fig. 58, *c*, *a*), and the bottom is during digestion filled with molecular matter and a few cells, *d*. Other tubular glands are also found in the stomach, which are believed to secrete mucus.

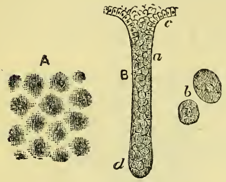

Fig. 58.—A, inner surface of the stomach, shewing the cells after the mucus has been washed out, magnified 25 diameters. B, gastric gland from the middle of the human stomach, magnified highly: *a*, wall of the tube, lined with large oval nucleated cells; *b*, the same cells isolated; *c*, nucleated cells of columnar epithelium, occupying the upper parts of the tubes; *d*, blind extremity of the tube.

88. *Action on Food in Stomach.*—When food is introduced into the stomach, it is subjected to three actions—first, to heat, the temperature of the stomach being, during digestion, about 99° F.; second, to a slow movement round and round, so as to bring the food into contact with the lining; and, third, to the chemical action of a special fluid—the gastric juice.

The food on entering the stomach first passes into the cardiac end, thence along the greater curvature from left to right to the pyloric end, and from thence along the lesser curvature from right to left.

89. The changes in the mucous membrane are: The inner surface of the healthy fasting stomach is of a paler pink than after the introduction of food, which causes the

exudation of a pure, colourless, viscid fluid, having a well-marked acid reaction. This fluid, which is the *gastric juice*, collects in drops, which trickle down the walls, and mix with the food. Its two essential elements are : (1) a free acid, which in some cases seems to be hydrochloric alone, and in others a mixture of hydrochloric and lactic acids ; and (2) an organic matter called *pepsin*, which is highly nitrogenous, and allied to the albuminates.

90. *Action of Gastric Juice.*—The uses of this fluid are not only to dissolve but also to modify the nitrogenous elements of the food (such as albumen, fibrin, casein, and, in short, all animal food except fat), converting them into new substances, termed *peptones*, which, although they coincide in their chemical composition, and in many of their physical properties, with the substances from which they are derived, differ essentially from them in their more ready solubility in water, in their power of rapidly dialysing, or passing through animal membranes, and in various chemical relations.

The gastric juice exerts no action on the fats and the carbo-hydrates (sugar, starch). If the fats or starches are in cells, the walls of which are formed of albumen, the walls are dissolved, and the contents set free.

91. *Case of Alexis St Martin.*—The process of gastric digestion was studied in 1838 by Dr Beaumont and others in the remarkable case of Alexis St Martin, a man who had an injury which left a permanent opening into his stomach, guarded by a little valve of mucous membrane. Through this opening, the mucous membrane could be seen, the temperature ascertained, and numerous experiments made as to the digestibility of various kinds of food.

92. *Absorption in the Stomach.* — What becomes of the matters that are thoroughly dissolved in the stomach? The albuminates, &c. which are converted into peptones, are for the most part taken up by the blood-vessels of the stomach, and by another set of vessels in the bowel called the *lacteals*. The rapidity with which aqueous solutions of iodide of potassium, the alkaline carbonates, lactates, citrates, &c. pass into the blood, and thence into the

urine, saliva, &c. shews that the absorption of fluids must take place very shortly after they are swallowed ; and there is little doubt that the blood-vessels (capillaries) of the stomach constitute the principal channel through which they pass out of the intestinal tract into the blood.

93. *Time required for Digestion.*—There can be no doubt that the stomach is admirably adapted for the digestion of the food introduced into it, because it has been shewn by numerous experiments that digestion will go on in gastric juice out of the stomach, but that it requires three or four times longer a period than when performed by the stomach itself. In the stomach, in most individuals, rice and tripe are digested in one hour ; eggs, salmon, and venison in one and a half hours ; tapioca, liver, fish in two hours ; lamb, pork, and turkey in two and a half hours ; beef, mutton, and fowl in three and a half hours ; and veal in four hours. There are, however, considerable differences in various individuals, or even in the same individual at different times.

94. *Conditions favourable for Good Digestion.*—These are : (1) a temperature in the stomach itself of about 100° F. ; (2) constant movement of the walls of the stomach, so as to bring the food thoroughly into contact with the mucous membrane and gastric juice ; (3) the removal from time to time of such portions as have been fully digested ; (4) a state of softness and minute division of the food ; (5) the quantity of food taken—the stomach should be moderately filled, but not distended ; (6) the time which has elapsed since the last meal, which should always be long enough for the food of one meal to have completely left the stomach before another is introduced ; (7) the amount of exercise previous and subsequent to a meal, gentle exercise being favourable, while over-exertion is injurious ; (8) the state of the mind, tranquillity of temper favouring good digestion ; (9) the general state of the bodily health, the stomach of an invalid not being usually so fit for digestion as that of a person in robust health ; and (10) the period of life, digestion being more active in the young than in the old.

95. *Form of the Stomach in various Animals.*—The form and dimensions of the stomach correspond to the kind of food on which the animal lives. *Carnivorous* animals, such as the hyena (fig. 59, B), have a simple stomach, as their food is easily digested ; while those which live on vegetable food, or *herbivora*, such as a

sheep, have complex stomachs, in which the food, so unlike the tissues of the body, may be thoroughly macerated and acted on by the gastric juice. In the ruminant, the food, when first swallowed, passes into the *rumen* or paunch (fig. 59, A, 1), where it is mixed with water and allowed to macerate. The *reticulum* or honeycomb bag, 2, is a kind of addendum or diverticulum to the rumen, and it appears to be specially connected with mixing the food with water. After a time, the food passes up into the mouth in the form of balls or boluses, where it is thoroughly masticated. This is the act of *rumination*. It is swallowed a second time, but it now passes into the *omasum* or manyplies, 3, where it is triturated and strained from excess of fluid. It then passes into the *abomasum* or true stomach, 4, where true gastric digestion takes place. The stomach of man much resembles that of carnivora.

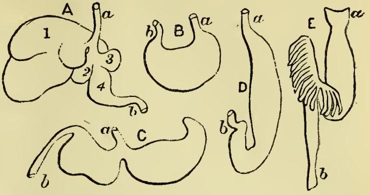

Fig. 59.—Stomachs of various Animals: A, sheep; B, hyena; C, hamster; D, seal; E, a salmon: *a*, cardiac opening or lower end of œsophagus; *b*, pyloric opening or beginning of duodenum. In A, a ruminant stomach, 1 is the *rumen* or *paunch*; 2, the *reticulum*; 3, the *omasum* or manyplies; and 4, the *abomasum* or true stomach.

DIGESTION IN THE BOWELS.

96. After the food, by digestion in the stomach, has been converted into a semi-fluid mass called the chyme (Gr. *chymos*, juice), it passes into the intestine. The length of the human intestine is usually about twenty-five feet. As a general rule, it may be stated that the intestines of herbivora are much longer than those of carnivora. This is due to the nature of the food. In those animals, such as the ox, which live on a food very different, physically and chemically, from the tissues of the individual, a complicated digestive apparatus and a long intestinal tube will be found; whereas those which live on food readily converted into their own tissues (such as a weasel, which preys on the blood of other animals), have a simple digestive apparatus and a short tube.

97. *General Description of Intestine.*—The human intestine consists of a convoluted tube, which, from a great change in calibre in two different parts, is divided into (1) the small intestine, and (2) the great intestine (fig. 25, p. 28). The small intestine is about twenty feet in length, and is divided by anatomists into three portions—the *duodenum*, *jejunum*, and *ileum*, the last opening into the great intestine. The whole of this tube is connected with the back of the abdominal cavity by a thin web, called the *mesentery*, on which blood-vessels, nerves, and absorptive vessels called lacteals, ramify before penetrating into and supplying the bowel.

98. *Microscopical Structure of Mucous Membrane.*—

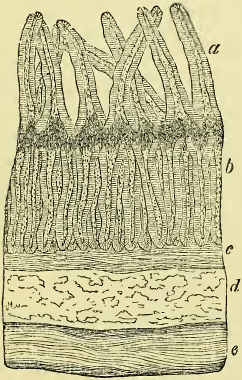

Fig. 60.—Vertical and Longitudinal Section of the small Intestine in the lower part of the Jejunum, shewing the general arrangement of its coats: *a*, villi; *b*, intestinal tubes or follicles of Lieberkühn; *c*, sub-mucous areolar tissue; *d*, circular muscular fibres; *e*, longitudinal muscular fibres.

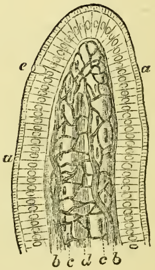

Fig. 61.—Diagrammatic View of the upper part of a *Villus: a a*, columnar epithelium; *e*, *goblet* cell; *b b*, artery and vein; *c*, nuclei of connective tissue; *d*, commencement of lacteal.

When the small intestine is slit open, it presents a large number of transverse folds, called *valvulæ conniventes*,

which are simply doublings of the mucous membrane, so as in little space to increase the surface for absorption. It has also a peculiar velvety appearance, which is due to the fact that it is covered over by innumerable small projections termed *villi* (fig. 60, *a*). They are more numerous in the upper than in the lower portions of the bowel. When examined by the microscope, they are found to be prolongations of the mucous membrane, shaped like the finger of a glove, and each is covered by a layer of epithelial cells (fig. 61, *a*, *e*). Of these there are two kinds : (1) the columnar epithelial cell (fig. 61, *a a*), and (2) a peculiar cell, with an open mouth, called a *goblet* cell (fig. 61, *e*). In the centre we find the commencement of the true absorbent vessel, called a *lacteal* (fig. 61, *d*), and surrounding it a network of vessels of very minute size. The villi in the small intestine are to a certain extent comparable to the delicate rootlets of a plant. The latter absorb moisture and soluble nutriment from the soil, while the former are bathed in a nutritious fluid, the chyme, and absorb readily fluids by the blood-vessels, and fatty matters by the lacteals. We find also scattered in large numbers over the mucous membrane, minute tubular glands called *Lieberkühnian glands*, after the anatomist Lieberkühn, who first described them (fig. 60, *b*). In the upper part of the duodenum, there are a few glands, like small clusters of grapes, called Brunner's glands, the function of which is unknown.

The great intestine, about five or six feet in length, is so termed because it is so much wider than the smaller one. It is also divided into three parts : the *cæcum*, which is a wide pouch, often of great size in herbivorous animals, and into which the small intestine opens, the entrance being guarded by a valve ; the *colon*, which forms the greater part of the large intestine ; and the *rectum*, which is situated entirely in the pelvis, and terminates in the anus. The great resembles the small intestine in general respects.

99. *Functions of Villi.*—There is abundant evidence that the function of the villi is connected with absorption, and mainly with the absorption of fatty matters. (1) The

villi exist only in the small intestine where the absorption of food goes on. (2) They are turgid, enlarged, and opaque during the process of digestion and absorption, and small and shrunken in animals that have been kept fasting for some time before death.

100. *Functions of Muscular Coat.*—The function of the coats is to propel the food along the bowel. This they perform by alternate contractions and relaxations, and thus a wave-like motion is produced. This motion may be readily seen in the intestines of an animal recently killed, and is termed a *peristaltic action.*

In the walls of the bowel, numerous minute ganglia and networks of nerves have been discovered. These nerves are distributed to the muscular fibres and to the glands, and the ganglia may act as local centres for reflex movements. The ganglia are also in connection with the cerebro-spinal and sympathetic systems of nerves.

101. *Action of Fluids in Small Intestine.*—When the food, reduced to a pulpy mass in the stomach, termed chyme, passes into the duodenum, it is mixed with three fluids—the bile, the pancreatic juice, and the intestinal juice.

102. *Function of the Bile in Digestion.*—The *bile* is an

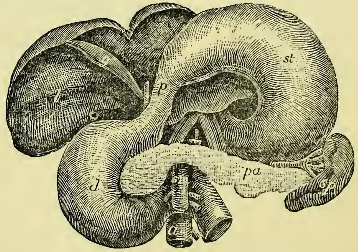

Fig. 62.—The under surface of the Stomach and Liver, which are raised to shew the Duodenum and Pancreas: *st*, stomach; *p*, its pyloric end; *l*, liver; *g*, gall-bladder; *d*, duodenum, extending from the pyloric end of the stomach to the front, where the superior mesenteric artery (*sm*) crosses the intestines; *pa*, pancreas; *sp*, spleen; *a*, abdominal aorta.

alkaline fluid secreted by the *liver* (the structure of which will be described in connection with the subject of *excretion*,

with which it has chiefly to do), and, after having been collected in the gall-bladder (fig. 62, *g*), finds its way into the upper part of the small intestine by a duct, which usually unites with that of the pancreas, *pa*, and opens by a common orifice. As it flows from the liver, the bile is a thin greenish-yellow fluid, sometimes olive-brown ; but when acted on by the gastric juice, it acquires a distinctly yellow or green hue, hence the appearance of vomited bile. Its main use seems to be (1) to promote the digestion of fatty matters, and it accomplishes this end by a peculiar physical action both on the fats and on the intestinal walls, disintegrating the former, and impressing on the latter (by moistening the villi) a peculiar condition which facilitates the absorption of fatty matters. (2) The bile separates nutritious matters from those which are non-nutritious, while it (3) stimulates the muscular movements of the bowels and (4) arrests putrefaction in the fæces.

103. *Function of the Pancreatic Juice in Digestion.*—The *pancreatic juice* is secreted by a long, narrow, flattened gland called the *pancreas*, or sweetbread, which lies deeply in the cavity of the abdomen, immediately behind the stomach (fig. 62, *pa*). It is a lobulated or *racemose* gland, consisting of an immense number of small pouches grouped round the extremities of small ducts. These ducts unite with others, becoming larger and larger, until the great duct of the gland is formed. The secretion is a colourless, clear, somewhat viscid, and ropy fluid, devoid of any special odour, and exhibiting an alkaline reaction. It contains a peculiar principle called *pancreatin*. The function of the pancreatic juice is (1) to emulsionise the fat of the chyme, and thus promote its absorption. If the duct of the pancreas be tied, and fat be taken as food, a large amount of it will appear in the fæces ; and the same result has been seen in the human being in cases of diseased pancreas. The juice appears not only *physically* to emulsionise the fats, but *chemically* to split them up into glycerin and a fatty acid. (2) The pancreatic juice also converts any starchy matter, which may have escaped the action of the saliva, into grape-sugar. (3) It acts partially on the albuminous

matters, splitting up the peptones into simpler bodies, such as leucin and tyrosin.

104. *Function of the Intestinal Juice.*—Of the last of the fluids poured into the intestine, the *intestinal juice*, we know little. It is the aggregate secretion of the various glands which occur in the walls of the smaller intestine. It is a colourless, or sometimes yellowish, ropy, viscid fluid, which is invariably alkaline. It seems to unite in itself the leading properties of the pancreatic and gastric juices; that is to say, it resembles the former in converting starch into sugar, and the latter, in converting albuminous bodies into peptones.

105. *Function of Great Intestine.*—The line of demarcation between the small and large intestine is very obvious, and by the peculiar arrangement of the *ileo-cæcal valve*, which guards the entrance of the small into the great intestine, matters are allowed to pass forward with facility, while regurgitation is impossible. Structurally, the great intestine has no villi, and is more capacious, though much shorter than the small intestine. Its contents differ very materially from those which are found in the small intestine, and constitute the *fæces*. They are more solid and homogeneous, and are often moulded into a definite shape. The only essential change which the matters in the great intestine undergo in this part of their course is, that they increase as they pass onward in solidity, in consequence of the absorption of fluid from them by the vessels of the mucous membrane. They are propelled onwards into the rectum by the vermicular action which has been already described, and are at last expelled by a voluntary effort.

The fæces consist partly of undigested materials (such as vegetable cellular tissue, fragments of tendon, skin, and disintegrated muscular fibre), and partly of matters which are derived from the mucous membrane of the great intestine. It is in the great intestine the chyme first acquires a fæcal odour, which is said to be due chiefly to the decomposition of albuminous matters, and which increases in intensity as the material passes along the bowel. This odour is not due simply to putrefaction, but to the presence

of peculiar effete matters, which are thrown off by the lining membrane of the bowel.

The colour of the fæces varies with the food. With a mixed diet, they are of a yellowish-brown tint ; on a flesh diet, much darker ; and on a milk diet, yellow. Their reaction is usually alkaline. About four and a half ounces in ordinary circumstances are voided daily.

ABSORPTION OF NUTRITIOUS MATTER.

106. As the chyme is propelled along the alimentary canal, the watery portion, holding various substances in solution, is absorbed by the *blood-vessels*, while the fatty matter is taken up by the *lacteals*. It is believed that this absorptive action, so far as the blood-vessels are concerned, is really a physical process dependent on osmotic action. The absorption of fatty matter appears to depend on the activity of the epithelial cells covering the villi. The whole of the nutritive material thus separates itself into two parts : one which passes directly into the blood, and the other which enters the lacteals, and in these becomes a milky fluid called the *chyle*. It is important to remember that all the blood circulating in the digestive organs, and taking up soluble nutritive matters, must pass through the liver before entering the general circulation, and from it the cells of the liver select and elaborate their secretions. But the chyle passes into the blood indirectly. It is first conveyed to numerous glands in the neighbourhood of the intestines, called *mesenteric glands* (see SANGUIFICATION). Before entering these glands it is a milky fluid, essentially molecular ; but after it has passed through the glands it is found to contain small granular cells, somewhat similar to colourless blood-cells, termed *chyle corpuscles*, along with much molecular matter, known as the *molecular basis of the chyle*. Before passing through the glands, the chyle does not coagulate on heating, but after doing so it coagulates readily. The

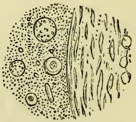

Fig. 63.—Drop of Chyle: On the left, corpuscles lying amongst molecular matter; on the right, corpuscles altered by the addition of acetic acid.

lacteal vessels proceeding from these glands unite with corresponding sets of vessels from the lower limbs, called *lymphatics*, in a wide cavity opposite the last dorsal vertebra, the *receptaculum chyli.* From this cavity a duct, the *thoracic duct*, ascends through the thorax, receives branches from the left arm and left side of the head, and unites with the venous system at the root of the neck on the left side, the point of junction being where the left internal jugular vein unites with the great vein of the left arm, the left subclavian. The lymphatics of the rest of the body unite to form the right lymphatic duct, which joins the venous system at a corresponding point on the opposite side of the root of the neck. The whole of the chyle, therefore, passes into the blood at the root of the neck; from thence it goes through the right side of the heart to the lungs, where the corpuscles probably acquire colour, and become the coloured corpuscles of the blood. This, however, is still a doubtful point.

SANGUIFICATION.

107. By this term we mean the making of blood. In the lowest animals, such as in the amœba, we find no circulating nutritious fluid. When we ascend higher in the scale, we find a colourless fluid containing molecules moving in certain definite directions by the action of cilia in the general cavity of the body, as in a sea-anemone. Still higher we meet with a colourless fluid circulating in vessels, frequently communicating with the body-cavity, and propelled by a special contractile organ, as in the sea-urchin or ascidian; and at last we meet with a coloured fluid, circulating in vessels separate from the body-cavity, and having a propelling organ, or heart, of more or less complex structure, as in all the vertebrata.

108. *Source of Blood.*—The blood, in the higher animals and in man, is derived from five sources: (1) from materials absorbed by the lacteals in the primary digestion of the food in the alimentary canal (chyle); (2) from soluble matters, such as water, soluble mineral matters, sugar, and peptones, absorbed by the blood-vessels, and first of all

sent through the liver; (3) from the matters formed by certain glands called blood-glands, found in various parts of the body; (4) from materials re-introduced into the blood from the tissues—products of the decomposition and solution of portions of these tissues consequent on their vital activity (lymph); and (5) from a small amount of matter which may be absorbed by the skin.

109. *The Blood-glands.*—The so-called blood-glands are —the *spleen*, a large organ found almost in juxtaposition with the left end of the stomach; the *suprarenal capsules*, two organs found in the lumbar region, one on the top of each kidney; the *thymus*, a gland found in the thorax, immediately behind the breast-bone, of larger size before

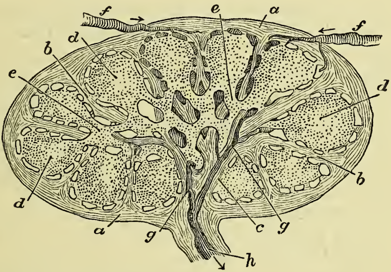

Fig. 64.—Section of a Lymphatic Gland: *a, a,* strong fibrous capsule sending partitions into the gland; *b,* partitions between the follicles or pouches of the *cortical* or outer portion; *c,* partitions of the *medullary* or central portion; *d, e,* masses of proto-plasmic matter in the pouches of the gland; *f, f,* lymph-vessels which bring lymph *to* the gland, passing into its centre; *g,* confluence of those leading to the efferent vessel, *h,* which carries the lymph away *from* the gland.

birth and during the earlier years of life than during adult life; the *thyroid*, a gland existing in front of the box of the larynx; the *pituitary* and *pineal* glands, found in the brain; the *glands of Peyer*, in the mucous membrane of the small intestine; and lastly, the *lymphatic glands*, which we find in many parts of the body, such as in the groin, the armpit, and the neck. The structure of a lymphatic gland will be

understood from the description of fig. 64. All of these glands agree in certain points of their anatomy : they have no ducts to carry off the secretion, except we regard as such the numerous lymphatics by which they are supplied ; they consist essentially of shut sacs, containing numerous molecules, nuclei from which cells may be developed, and fully formed cells resembling white blood-corpuscles ; and finally, they are richly supplied with blood-vessels, lymphatics, and nerves. That they are really connected with the formation of blood, more especially of the colourless corpuscles, is probable from the fact, that in a disease known as *leucocythæmia*, in which there is a great increase in these cells, we find also that one or more or all of the blood-glands are much enlarged.

110. *Nature of Lymph.*—The various tissues of the body are nourished by blood brought into close proximity to them by minute vessels termed *capillaries.* While the blood is passing through the capillaries, part of it transudes through their walls to nourish the tissues. A portion of this fluid or *plasma* is taken up by the tissues, and the other portion is left behind, constituting the fluid found in almost every tissue, to which it owes its softness and moistness. The tissues perform certain functions, and in doing so undergo disintegration, and their materials pass into a fluid condition. This fluid matter resulting from the disintegration of the tissues, together with the excess of nutritious fluid which has transuded from the vessels, is called *lymph*, and is taken up by the commencements of a number of minute vessels termed *lymphatics.* The lymphatics carry the lymph to glands distributed here and there throughout the body, called *lymphatic* glands, where it is acted upon in such a manner as to fit it for being carried back again into the blood. Thus the lymph results partly from matters produced by the tear and wear of the tissues, and thus the economy uses up, as in a manufactory, its waste products as far as possible. The kernels or swellings in the arm during a whitlow, or after poisoning, are swollen lymphatic glands. The lymphatic glands of the mesentery, or web connecting the bowel with the body, elaborate chyle, not lymph, and are termed *mesenteric* glands.

111. *Structure of the Spleen.*—This is the largest and most important of the blood-glands. It is of an oblong flattened form (fig. 62, *sp*, p. 74), soft, of very brittle consistence, highly vascular, of a dark bluish-red colour, and situated near the cardiac or left end

of the stomach. On cutting into it, a section shews the presence of numerous fibrous bands termed *trabeculæ*, united at numerous points with one another, and running in all directions. The *parenchyma*, or proper matter of the spleen, occupies the interspaces of the above-described areolar framework, and is a soft pulpy mass of a reddish-brown colour, consisting of coloured and colourless blood-corpuscles, and much molecular matter. The venous blood of the spleen is carried away by the splenic vein, which contributes to form the great portal venous system carrying blood to the liver; while arterial blood is supplied by the splenic artery. The branches of the latter subdivide and ramify like the branches of a tree (fig. 65), with the *Malpighian* or *splenic corpuscles* attached to them like fruit (*c*, *c*, *c*). These corpuscles, originally discovered by Malpighi, are whitish, spherical bodies, ranging from one-third to one-sixth of a line in breadth, and filled with a soft, white, semi-fluid substance, made up of granular matter, nuclei similar to those found in the pulp, and a few nucleated cells (fig. 66). Various theories have been advanced as to the functions of the spleen; but the one most generally adopted is, that it has to do with the formation of colourless corpuscles of the blood. How it may thus act we do not know. Occasionally, in spleen pulp, we meet with large cells similar to *d* (fig. 66), inclosing two or three cells similar to blood-corpuscles. It is to be noted that the spleen has been removed successfully from animals without any marked disturbance of the system. In these circumstances the other blood-glands probably did its work.

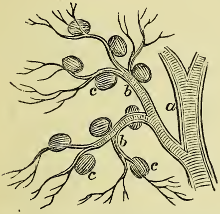

Fig. 65.—Portion of Splenic Artery, *a b b*, having Malpighian bodies attached, *c*, *c*, *c*.

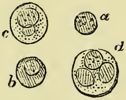

Fig. 66.—Cells from the Spleen Pulp: *a*, similar to a colourless corpuscle of blood; *b*, nucleated cell; *c*, binucleated cell; *d*, cell containing three cells in interior.

THE BLOOD AND ITS CIRCULATION.

112. The blood formed in the manner just described, is the most important and most abundant fluid in the body. With the exception of a few tissues, such as the centre of the cornea of the eye, the nails, and the hair, it pervades every part of the body, as may be shewn in the case of the skin by puncturing any part of it with a needle. The total quantity is estimated at about one-eighth of the weight of the body, or about 20 pounds in a man of average size. Its colour is red, but it varies from a bright scarlet in the arteries to a dark purple in the veins. When, however, a minute drop is examined under the microscope, it is seen to be made up of, first, a clear colourless fluid; and, secondly, of a multitude of small solid bodies or corpuscles, which float in the plasma. This plasma, called *liquor sanguinis*, is composed of water richly charged with materials derived (through the chyme) from the food; namely, albumen, fibrin, various fats, &c. The greater part of the blood—about 70 per cent.—is made up of water. It contains a very small amount of fibrin, about 7 per cent. of albumen, 14 per cent. of corpuscles, and the remainder consists of extractive matters, fats, and various salts.

113. *Microscopical Appearance of Blood.*—The great majority of the corpuscles are of a yellowish-red colour, and by their enormous number impart a red hue to the blood; while a few are white or colourless. The red corpuscles have a diameter of about $\frac{1}{3500}$th of an inch, being about $\frac{1}{4}$th of that fraction in thickness; and in form they are circular biconcave discs (fig. 67, *a*), and in freshly drawn blood they arrange themselves by contact of their flat surfaces into little rolls like piles of coins (fig. 67, *e*). The colourless corpuscles are larger, globular or irregular in form, and present a granulated appearance (fig. 67, *d*). Recently it has been shewn that these are little masses of living protoplasm, capable of spontaneous movement, and that they are identical with the corpuscles found in purulent matter or pus (p. 33). In all classes of animals the colourless corpuscles are alike; but the form of the coloured

corpuscles varies, being oval in fishes, reptiles, and birds (fig. 68). In all mammals they are circular, with the exception

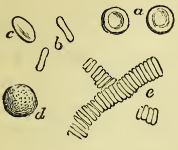

Fig. 67.—Blood-corpuscles; *a*, two coloured corpuscles shewing shadowed appearance in the centre, indicating biconcave form; *b*, corpuscle seen edgeways; *c*, slightly oval corpuscle; *d*, colourless corpuscle; *e*, coloured corpuscles in rouleaux.

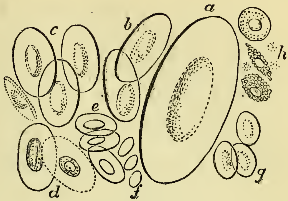

Fig. 68.—Blood-corpuscles of various Animals magnified to the same scale: *a*, from proteus; *b*, salamander; *c*, frog; *d*, frog after addition of acetic acid, shewing nucleus; *e*, bird; *f*, camel; *g*, fish; *h*, crab or other invertebrate animal.

of the camels and llamas, where they are oval (fig. 68, *f*).

114. *Blood-corpuscles of Various Animals.*—The coloured blood-corpuscles of all mammals have no nucleus, swell up and become globular on the addition of water, and almost entirely disappear in weak acetic acid. The coloured corpuscles of birds, reptiles, and fishes have a nucleus which is readily seen on the addition of water or acetic acid. Acetic acid renders the body of the colourless corpuscle clear and transparent, and reveals the existence of two or more nuclei, usually clustered together.

115. *Coagulation of the Blood.*—Shortly after its removal from the body, the blood begins to thicken or coagulate, and soon separates into two distinct parts, one of them being a dark-red jelly or *clot*, which is the heavier of the two, and sinks; while the other is a clear straw-coloured fluid, called the *serum*, which covers the clot. This depends on the formation of a substance called *fibrine*, which forms a meshwork of fine molecular fibres, entangling the corpuscles. When a coagulum appears, fibrine is produced by the union of two substances present in solution, one called *fibrinogen*, and the other termed *fibrino-plastic* substance, the latter probably being a substance known as *globulin*, which forms a large part of the coloured corpuscles.

This remarkable property of coagulation is the chief cause of the arrest of bleeding from a wound.

Circulation of the Blood.

116. The blood is in constant motion in a definite direction during life, and the motion is known as the *circulation.* Its true course was discovered by Harvey, about 1620. The organs of circulation are the heart, arteries, veins, and capillaries. We will first briefly describe the structure of these, and then treat of the mechanism of the circulation.

117. *The Structure of the Blood-vessels.*—Of these there are three kinds—capillaries, arteries, and veins. The *capillaries* are delicate tubes, about the diameter of a blood-corpuscle (fig. 69, *d*), apparently formed of homogeneous transparent membrane, with nuclei imbedded here and there in the wall; but recent researches have shewn that they are composed of flattened cells, adhering

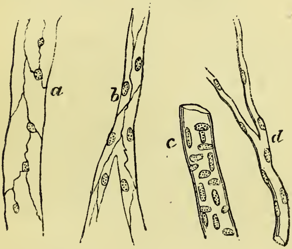

Fig. 69.—Capillaries of various size: *a*, capillary much magnified and acted on by nitrate of silver, so as to shew that it is made up of flattened cells; *b*, a smaller vessel shewing the same; *c*, a small artery or vein shewing transverse and longitudinal nuclei; *d*, ultimate capillary from *pia mater* of sheep's brain.

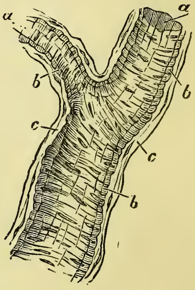

Fig. 70.—An Artery of intermediate size: *a*, *a*, openings of branches and position of lining of vessel; *b*, *b*, *b*, muscular coat shewing transverse nuclei; *c*, *c*, coat of connective tissue.

edge to edge (fig. 69, *a*, *b*). The edges of these cells may be made apparent by nitrate of silver injection (see p. 37). In vessels somewhat larger we find outside of the lining (which is composed of *endothelial* cells, see p. 37) a delicate, transparent, and fragile membrane which tends to curl upon itself from its elasticity. It is

perforated by numerous small holes. Outside of this there is a layer of muscular fibre-cells arranged longitudinally and transversely, the nuclei of which are seen after the addition of acetic acid (fig. 70). This constitutes what is usually termed the *muscular coat*. In large arteries, we find outside of, and intimately connected with, the muscular coat a thick layer of yellow elastic tissue, which gives great elasticity to these vessels; and most externally there is a layer of connective tissue. As the vessels are traced towards their capillary terminations, they gradually lose their connective tissue and elastic coats. In small arteries the wall is composed entirely of two layers of longitudinal and circular muscular fibre-cells, lined by endothelial cells, and in the ultimate capillary these fibre-cells have disappeared, and there is only a thin wall formed of endothelial cells, as above described. Veins differ from arteries chiefly in the comparative thinness of their coats. It is important to bear in mind that the predominant feature of the larger arteries is *elasticity*, while that of the smaller is *contractility*. The ultimate capillaries are also independently contractile.

118. *The Position and Structure of the Heart.*—This organ is situated in the thorax or chest, between the two lungs, and, together with portions of the great vessels which convey blood to and from it, is inclosed in a membranous bag, the *pericardium*. It is a hollow organ, having muscular walls. The following anatomical points may be clearly made out on the heart of an ox or of a sheep, a demonstration of which will teach far more than we can hope to explain in these pages. It is divided (fig. 71) by a septum into a right and left half, each of which is again subdivided by a transverse partition into two compartments, communicating with each other, named the *auricle*, *d*, *k*, and *ventricle*, *a*, *m*. The apex of the heart may be felt in the living man between the cartilages of the fifth and sixth ribs, a little below and to the inner side of the left nipple.

The heart is a double organ, composed of a right and left part, each consisting of an auricle and ventricle. These are named, in the order in which the blood passes through the heart, *right auricle*, *d*; *right ventricle*, *a*; *left auricle*, *k*; and *left ventricle*, *m*. Into the right auricle, blood passes by the following openings: (1) from the head, neck, and upper

extremities by the *superior vena cava, f;* from the lower part of the body by the *inferior vena cava, b,* and from the wall of the heart itself by numerous small veins. The blood passes from the right auricle to the right ventricle through an opening in the partition between the auricle and ventricle known as the *right auriculo-ventricular opening,* which is guarded by a valve called the *tricuspid valve.* From the right ventricle the blood is sent to the lungs through the *pulmonary artery, i,* and it is returned from the lungs to the left auricle by four *pulmonary veins, e, e′,* and from thence to the left ventricle through an opening in the septum between the auricle and ventricle, called the *left auriculo-ventricular opening,* where we find a valve corresponding to the tricuspid on the right side, but composed of two flaps instead of three, and hence called the *mitral* valve, from its fancied resemblance to the upper part of a bishop's mitre. At or a little above the orifices of the pulmonary artery and of the aorta, we find valves which, from their shape, are termed the *semilunar valves.*

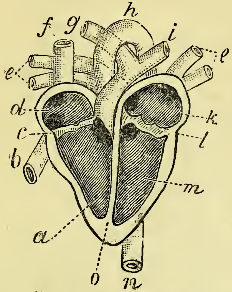

Fig. 71.—Theoretical section of the Human Heart: *f, b,* the two *venæ cavæ,* opening into *d,* the right auricle; *c,* the tricuspid valve; *a,* the right ventricle, from which proceeds the pulmonary artery, dividing into branches *g* and *i,* going to the right and left lung respectively; *e, e′,* the pulmonary veins (two from either lung), entering into the left auricle, *k; l,* the mitral valve; *m,* the left ventricle, from which proceeds the aorta, whose arch is indicated by *h,* and the descending portion by *n,* none of its branches being indicated in this figure; *o,* the partition, or *septum,* between the right and left hearts.

The substance of the heart is composed of a spiral arrangement of no less than seven layers of muscular fibre. When the ventricles contract, the blood is propelled from them, not in a direct manner, but with a sort of spiral motion, as if it were really wrung out of the heart.

119. *General Description of the Course of the Circulation.* —This may be studied with the aid of a diagram (fig. 72),

which is equally applicable for all other mammals as well as for man and for birds. The shaded part of fig. 72 represents structures filled with impure or *venous* blood, while the unshaded portion represents structures in which pure oxygenated *arterial* blood occurs. In this diagram we observe a dotted circle, representing a closed bag or sac, termed the pericardium, and inclosing the four cavities, *c*, *v*, *c'*, *v'*, of which the heart is composed. Two of these cavities, *c* and *c'*, are for the purpose of receiving the blood as it flows into the heart, and are termed the *auricles;* while the two cavities, *v* and *v'*, are for the purpose of propelling the blood through the lungs and general system respectively, and are termed the *ventricles.* The vessels that transport blood into the auricles are termed *veins;* and the vessels through which blood is driven onwards from the ventricles are known as *arteries.* The diagram further shews that what we commonly term the heart is in reality *two distinct hearts* in apposition with each other; one, shaded in the figure, which is called the right, or venous, or pulmonary heart; and the other, unshaded, which is called the left, or arterial, or systemic heart, the last name having been given to it because the blood is sent from it to the general system; just as the right heart is termed pulmonary from its sending blood to the lungs.

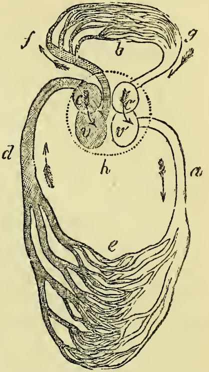

Fig. 72.—Mode of Circulation in Man and other Mammals, and in Birds: *h*, heart; *v*, right ventricle; *v'*, left ventricle; *c*, right auricle; *c'*, left auricle; *a*, aorta; *d*, vena cava; *e*, greater circulation; *b*, smaller circulation; *f*, pulmonary artery; *g*, pulmonary veins.

120. We will now trace the course of the blood as indicated by the arrows in this diagram, commencing with the right auricle, *c*. The right auricle contracting upon the venous or impure blood which has been returned from the body, and with which we suppose it to be filled, drives its contents

onwards into the right ventricle, *v*, through an opening between these two cavities, called the right auriculo-ventricular opening, which is guarded by a valve, named tricuspid, from its being composed of three pointed membranous expansions, which almost entirely prevents the regurgitation or reflux of the blood from the ventricle into the auricle. The ventricle, *v*, being now filled, contracts; and, as the blood cannot return into the auricle, it is driven along the shaded vessel, the dividing branches of which are indicated by *f*. This vessel is known as the pulmonary artery, and conveys the blood to the lungs. At its commencement it is guarded by valves, termed, from their shape, the semilunar pulmonary valves, which entirely prevent the blood which has once been propelled into the pulmonary artery from re-entering the ventricle. The pulmonary artery gradually divides into smaller and smaller branches, which ultimately merge into capillaries. In these capillaries, which are freely distributed over the external surface of all the air-cells (of which the lung is mainly composed), the venous blood is brought in contact with atmospheric air, gives off its carbonic acid gas (which is its principal impurity), and absorbs oxygen, by which processes it is converted into pure or arterial blood. The capillaries, *b*, in which the blood is arterialised, gradually unite to form minute veins, which, again, join to form larger vessels, until finally the blood is collected into four vessels, known as pulmonary veins (two from each lung), which pour their contents into the left auricle. Only one such vessel, *g*, is shewn in the figure, because the main object of this diagram is to illustrate the mode and general direction in which the blood circulates, not to indicate the special vessels through which it flows in different parts of the body. The blood, now fitted for the various purposes of nutrition, enters the left auricle, *c'*, which, by its contraction, propels it into the left ventricle, *v'*, through the left auriculo-ventricular opening. This opening, like the corresponding one in the right heart, is guarded by a valve, which, from its form, is termed the mitral valve, and which entirely prevents the reflux of the blood. The left ventricle, *v'*, contracts and drives its contents into the large

artery, *a*, which represents the aorta—the great trunk—which, by means of its various branches (none of which are indicated in the diagram), supplies every portion of the body with pure arterial blood.

121. From the aorta and its various subdividing branches the blood passes into the capillaries, *e*, which occur in every part of the system. In these capillaries it undergoes important changes, which may be considered as almost exactly the reverse of those which occur in the pulmonary capillaries; it parts with its oxygen, becomes charged with carbonic acid, and, as it leaves the capillaries and

Fig. 73.—Diagram shewing generally the course of the Circulation and some of the principal Vessels: H′, right ventricle; H, left ventricle; A, A, A, aorta; *k*, part of left auricle; P, pulmonary artery going to lungs; *v*, ascending or lower vena cava; *e*, trachea or windpipe; *a′*, *a*, right and left carotid arteries; *v′*, *v*, veins from root of neck (internal jugular and subclavian) joining to form descending or upper vena cava; *i*, hepatic artery; *l*, hepatic vein; I, superior mesenteric artery going to mesentery and bowels; L, portal vein going to liver; *k′*, renal artery; *k*, renal vein; V, inferior vena cava splitting into the two iliac veins.—OWEN.

enters the minute veins formed by their union, presents all the characters of venous blood. The veins gradually unite till they form two large trunks, termed the superior and inferior *venæ cavæ*, which pour their contents into the right auricle—the point from which we started. Only one of these great veins, *d*, is indicated in the diagram. We thus perceive that there is a complete double circula-

tion; that there is a lesser circulation effected by the blood in its passage from the right to the left heart through the lungs, and that there is a great circulation effected by that fluid in its passage from the left heart, through the system generally, to the right heart.

122. The position of the larger vessels in the thorax, abdomen, and at the root of the neck, may be studied in fig. 73, with the aid of the description of the figure.

123. *Influence of Elasticity of Arteries on the Circulation.* —But although the heart is the chief organ for propelling the blood, there are other forces at work. When the left ventricle contracts, blood is propelled into the aorta, which, however, contained blood at the time. This blood is pushed forwards, and the aorta dilates. When the propulsive power has ceased, the aorta, being a very elastic tube, recovers its original calibre. In doing so, it assists in forcing the blood onwards. Thus by successive portions of the larger arteries acting in the same manner, dilating with the impulse, and regaining their size by elasticity, the original mechanical force of the heart, which throws blood into the aorta in a series of successive jets, is converted into a uniform wave-like flow, which we term the pulse. The *pulse*, which beats about seventy times per minute, is the change produced in the diameter and length of an artery when it receives the wave of blood. The effect of the elasticity of the vessels is to convert the sudden spasmodic action of the contraction of the ventricle into a continuous uniform movement. Hence in the capillaries, as seen in the web of a frog's foot, there is no jet-like movement, but the blood flows onward in one continuous stream.

124. *Influence of the Tissues on the Circulation.*—The tissues also exert an attractive influence on the blood, drawing it forwards; and consequently we find that, wherever we have activity of growth in any part of the body, there is a determination of blood to that part. We see this in the congestion which precedes the annual growth of a stag's horn.

125. *Action of the Veins.*—After the blood has passed through the capillaries and into the veins, the power of the

heart has reached a minimum. The blood is now forced along the veins to the heart, chiefly by the pressure of the muscles. Many of the veins are provided with valves, which are so arranged as to allow the blood to flow only towards the heart; and, consequently, when a muscle contracts and presses on a vein, the blood is propelled forwards (fig. 74). Thus muscular exercise assists occasionally in removing venous congestions.

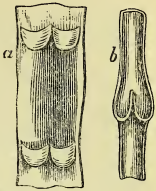

Fig. 74.—Valves in Veins: *a*, vein slit open, shewing semilunar valves; *b*, side view, shewing the valves closed.

126. *Influence of Respiration.*—Lastly, the movements of respiration affect the circulation; inspiration, by increasing the flow of blood along the great vessels to the heart; while expiration has the contrary effect.

127. *Rhythmic movements of the Heart.*—The auricles contract synchronously, that is, at the same time, and pour their blood into the ventricles. When these are full, they also contract synchronously, the right sending blood to the lungs and the left to the body.

128. *Conditions affecting the Pulse.*—Muscular exertion, if violent, quickens the pulse. It is more frequent in the erect than in the sitting position, and quicker then than in the recumbent posture. Sex appears to exercise an influence. The natural pulse in the adult male varies between 60 and 70 pulsations per minute, that of the female being on an average about 10 beats more. In the newly born infant it is from 130 to 140; in old age, from 50 to 60; but occasionally in old age it is much more rapid. The pulse is quicker in the morning than in the evening; it reaches its maximum about noon, and its minimum soon after midnight. The pulse is quickened by excitement, and sometimes slowed by fear. It is quickened in most diseases, especially so in those of a febrile character; but it is slowed usually in jaundice, and in cases of compression of the brain.

129. *Circulation in the Capillaries.*—Few sights are more beautiful than the circulation of the blood in the web of a frog's foot. The blood flows in a continuous stream, the coloured corpuscles chiefly in the centre of the vessels, while the colourless (much fewer in number) may be observed travelling more slowly at the side of the current, and occasionally clinging to the wall of the vessel (see p. 33). It has been estimated that the blood flows in the capillaries at the rate of about 1 inch per minute. In an artery it runs probably about 15 inches per second, and slower in a vein. The arrangement of the capillaries of the skin is seen in fig. 75. Each tissue and organ has its characteristic arrangement of these small vessels.

Fig. 75.—Arrangement of the Capillary Loops in the skin.

130. *Influence of the Nervous System on the Heart and Circulation.*—Space will not permit more than a brief outline of our knowledge regarding this important matter. All have observed how readily the heart is affected in the number of its pulsations by mental excitement, and how readily it sympathises with any inflammatory state occurring in almost any part of the body. This indicates that it must be under the control, so to speak, of some nervous arrangements. The heart of a frog will pulsate after the death of the animal, and even after it has been removed from the dead body and laid on a glass plate. This power of independent rhythmic contraction has been shewn to depend on the presence in the substance of the heart itself of small nerve centres called *ganglia.* If these be destroyed, the rhythmic movements cease. But recent observation has shewn that the heart, or rather the centres just referred to, are under the control of two sets of nerve filaments, one set belonging to the sympathetic system of nerves, and the other to the pneumogastric. If the *pneumogastric* be cut, the heart beats faster, and if the lower end of the cut nerve be stimulated, the heart beats slower, or it may stop altogether in a state of complete relaxation. On removing the irritation, it may again begin to beat. On the other hand, if the *sympathetic* be cut, the heart will beat slower, and if the lower cut end be stimulated, it will again

beat faster. These facts have led physiologists to the general conclusion that the sympathetic is the *motor* nerve of the heart, constantly stimulating the cardiac centres to work, while the action of the pneumogastric is the opposite—that is, it tends to restrain the action of these centres. This restraining action is said to be inhibitory, and the pneumogastric (or rather certain filaments in this great nerve) is now called the *inhibitory* nerve of the heart. To illustrate this simply, the sympathetic is to the heart what the spur is to the horse, urging him onward, while the action of the pneumogastric is like the bit and bridle, restraining him more or less. But the relations of the nervous to the circulatory systems are still more complicated. The blood-vessels are under the control of a system of nerve filaments in the sympathetic, termed *vaso-motor*, by the action of which on their muscular walls the calibre of the vessels is regulated. These *vaso-motor* fibres originate in the *medulla oblongata* at the base of the brain, from a spot termed the *vaso-motor* centre. It has recently been shewn that the action of this centre may be inhibited (or partially thrown out of gear, as it were) by the action of a set of filaments also in the pneumogastric, which carry impressions upwards from the heart to the brain. These filaments, in some animals, form a slender nerve, distinct from the pneumogastric below a certain point, now called the *depressor* nerve. The action of this nerve is probably as follows: Suppose, for example, that the smaller arteries throughout the body were in a state of such contraction that the blood could not pass quickly through them. In these circumstances the large vessels would become distended, the tension of the blood on their walls increased, and the heart would have to labour hard to force the blood onwards. When this condition occurs, an influence may be sent from the heart, along the *depressor* nerve, to the *vaso-motor* centre in the medulla, the effect of which is to inhibit this centre. The instant the centre is inhibited, the smaller blood-vessels relax, the blood flows more freely through them, the tension or pressure in the larger vessels is diminished, and the heart, having less resistance in front, works more easily. Thus we must regard the blood-vessels as a system of living tubes subject to such influences of the nervous system as the requirements of the tissues and of the heart demand.

RESPIRATION.

131. The organs and process of respiration now claim our attention. We have already stated that the blood of the

arteries differs in colour from that of the veins, the former being of a bright scarlet tint, while the latter is purplish in colour. The *arterial* represents pure, and the *venous* impure blood; the change from the former to the latter having taken place in the capillaries which form the bond of union between the termination of an artery and the beginning of a vein. The chemical differences between arterial and venous blood are slight, except in relation to the gases held in solution in these fluids. The two kinds of blood differ widely in this respect, there being a smaller quantity of oxygen, and a greater quantity of carbonic acid, in venous than in arterial blood.

132. The organs by which the impure and dark venous blood is converted into pure, bright scarlet, arterial blood, fit for nourishing the various tissues of the body, are the lungs, and the agent by which this change is effected is the oxygen of the air we breathe. In their simplest form, as they occur in certain reptiles, they are mere air-sacs, existing as two elastic membranous bags, having small honeycomb-like depressions on their inner surface, communicating with the external air by a tube known as the windpipe or *trachea*, which opens through the larynx or organ of voice into the throat. These bags are lined by a delicate, thin, and moist mucous membrane, in which is imbedded a network of capillaries, through which all the blood is in turn driven by the heart. The moist partition between the blood in this network and the air in the interior of the lungs, is so thin as to allow an interchange between the gases of the blood and the gases of the air—that is to say, oxygen passes from the air in the air-cells into the blood, while carbonic acid gas and aqueous vapour pass outwards from the lungs into the air in the air-cells. This is a purely physical phenomenon, dependent on the laws of diffusion and admixture of gases through animal membranes.

133. *General conditions of Respiration.*—In the higher animals and in man, these essential parts are much complicated and modified in a variety of ways. The anatomical details may be considered under the following heads: *Firstly*, the lungs must afford by their internal arrangement

an immense extent of internal mucous membrane, covered by vascular network, through which, as in the simpler form, the blood flows in innumerable minute streamlets, only separated by an extremely thin membrane from the atmospheric air that has been inhaled; *secondly*, there must be such an arrangement of the circulating system, that fresh blood may be perpetually driven from the right side of the heart through the lungs, and onwards to the left side of the heart; and *thirdly*, there must be arrangements for the frequent and regular change of the air contained in the lungs.

134. *General Anatomy of the Organs.*—We shall first consider the lungs and the passages leading to them. The back of the mouth or pharynx is connected with the outer air in two ways—namely, by the nasal passages and nostrils, and by the mouth. Through either of these channels the air may pass to and from the lungs, but the nostrils are, properly speaking, the entrances to the respiratory system. Behind the root of the tongue, we find a chink or aperture, the *glottis*, bounded laterally by two folds of membrane called the *vocal cords*, which may be more or less widely separated from each other (fig. 109). This chink or aperture is guarded by a leaf-like lid, the *epiglottis*, which can be closed when expedient, so as to prevent the entrance of particles of food, drink, &c. The glottis opens downwards, into a box-like chamber called the *larynx* (which is the organ of voice), and leading downwards from the larynx runs the *trachea*, or windpipe, which is kept permanently open for the passage of air, by cartilaginous rings, that surround the anterior two-thirds of it. These are united, and the back of the tube is formed by a fibrous membrane or muscle. The windpipe, which is easily felt by the hand, and lies just below the projecting part of the larynx, popularly known as Adam's apple, is about four and a half inches in length, and about three-fourths of an inch wide. Passing into the cavity of the chest, it divides into two branches, which are termed the right and left *bronchi* (fig. 76). Each bronchus enters the lung of its own side, and divides into a great number of smaller tubes, called the *bronchial tubes*, which again go on subdividing. These finest tubes end in elongated dilatations,

averaging $\frac{1}{40}$th of an inch in diameter, which are called the *air-cells* (fig. 77). If we can conceive a bunch of grapes with its stem and all its minute branches, and the grapes attached to the ends of them, to be hollow, we get a good idea of the mode in which the lung is constructed, except that it does not represent all the sacculation or partitioning of the terminal cells. It is in consequence of the air included in

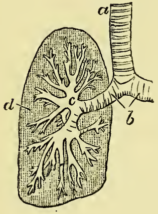

Fig. 76.—Diagram shewing *a*, trachea; *b*, division of trachea into two *bronchi*; *c*, still smaller bronchi; *d*, substance of the lung.

Fig. 77.—Ultimate structure of Lungs: *b*, small bronchus; *c*, external aspect; *d*, internal aspect of cluster of air-cells.

these cells that the lungs have their soft spongy feeling, and crackle when compressed between the fingers. Each lung is invested by its own investing serous membrane, termed the *pleura*, which serves the double purpose of facilitating the movements necessary in the act of respiration, and in suspending each lung in its proper position.

135. *General Description of Process.*—The *blood* is being perpetually changed and driven in a constant current through the lungs by the action of the heart, the venous or impure blood being collected in the right ventricle, and thence conveyed by the pulmonary artery into the lungs. In these, again, it gives off carbonic acid and aqueous vapour, and absorbs oxygen (as already described); and after these changes, it is collected, and returned to the left auricle by four vessels called the pulmonary veins (p. 87).

The mode in which the *air* is renewed in the lungs next

requires notice. This is effected by the respiratory movements, which consist in alternate acts of *inspiration* and *expiration*, with an intervening pause before the process is renewed. An adult man in a sitting position performs the respiratory act from thirteen to fifteen times in the minute, but much more rapidly if taking exercise. At each inspiration, about 30 cubic inches of air are inspired, and at each expiration nearly the same volume is exhaled, difference being allowed for temperature, which in the exhaled air may equal that of the blood. From 300 to 400 cubic feet of air thus pass through the lungs of a man at rest in the course of twenty-four hours, and these are charged with carbonic acid, and deprived of oxygen to the extent of nearly 5 per cent. ; or, to put it in another form, about 18 cubic feet of the one gas are taken in, and of the other gas are given off. The quantity of carbon thus excreted in the form of carbonic acid gas is nearly represented by eight ounces of pure charcoal. The amount of watery vapour separated by the lungs varies from six to twenty ounces daily, according to the diet, exercise, temperature, humidity of the air, &c.

136. *Mechanism of Respiration.*—The chest (or thorax, as it is termed by anatomists, fig. 12, p. 15) is so constructed as to be capable of enlargement in height (vertically), in depth (or from the front backwards), and in width (or from side to side). Its height is increased mainly by the descent of the diaphragm (fig. 25), and to a certain extent by the elevation of the ribs, and the widening of the intercostal spaces ; while its depth and width are increased by the elevation of the ribs, which carry forward and elevate the breast-bone (or sternum), especially at its lowest end, and are slightly rotated on an imaginary axis, joining their extremities, by which their central portion is raised, and slightly removed from the mesial plane of the chest. It is only in forced or deep inspiration that all these means of enlarging the chest are called into play. An ordinary inspiration is attended in men with very slight elevation of the ribs (about one-twentieth of an inch), while in women the elevation is much greater, especially in the upper ribs ; the cause of this difference in the sexes

probably lying in the narrower waist of the female requiring a compensation in the upper part of the chest. There are three varieties of ordinary respiration, namely, 1. *Abdominal*, or that chiefly effected by the diaphragm, and seen in the motion of the walls of the belly; 2. *Costo-inferior*, or that in which the seven lower ribs are observed to act; and 3. *Costo-superior*, or that effected in a considerable degree by the upper ribs. The first variety occurs in infants up to the end of the third year, and in males generally; the second, in boys after the age of three, and in men; and the third, in adult females. The difference between the depth of a forced and an ordinary inspiration is shewn in the accompanying figures (fig. 78).

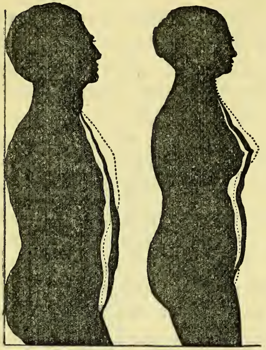

Fig. 78.—Diagrams (by Hutchinson) shewing the extent of Antero-posterior Movement in ordinary, and in forced Respiration in male and female. The back is supposed to be fixed, in order to throw forward the movement as much as possible. The black line indicates, by its two margins, the limits of *ordinary inspiration* and *expiration*. In *forced inspiration*, the body comes up to the dotted line, while in *forced expiration* it recedes to the smallest space indicated.

137. Every complete act of respiration is divisible into four parts—namely, 1. Inspiration; 2. A short pause, not always observed; 3. Expiration; and 4. A considerable pause, occupying about one-fifth of the whole time required for one complete respiratory act. The act of expiration is always more prolonged than that of inspiration, the former being to the latter in the ratio of 12 : 10 in adult males, and as 14 : 10 in children, women, and aged persons. The number of respiratory acts performed in a minute varies at different ages. At birth there are 44 respirations in one minute; at 5 years of age, 26; from 15 to 20, 20; from 20 to 25, 18·7; from 25 to 30, 16; from 30 to 50, 18·1: so that from 16 to 20 may be taken as the ordinary range for healthy adults. The average ratio which the number of respirations bears to the number of pulsations in a given time is about 1 : 4½, and if there be any great

deviation from this ratio, there is probably some obstruction to the aëration of the blood, or some disorder of the nervous system.

138. *Capacity of the Lungs.*—When the lungs have been emptied as much as possible of air by the most powerful expiratory effort, they still contain a quantity over which we have no control, and which may be estimated at about 100 cubic inches. To this portion of the contents of the lungs the term *residual air* is applied. In addition to this residual air, physiologists distinguish, in connection with the respiratory process, *supplemental air*, which is that portion which remains in the chest after an ordinary gentle expiration, but which may be displaced at will, 100 cubic inches; *breathing* or *tidal air*, which is the volume that is displaced by the constant gentle inspiration and expiration, about 30 cubic inches; and *complemental air*, or the quantity which can be inhaled by the deepest possible inspiration, over and above that which is introduced in ordinary breathing, 100 cubic inches. The greatest volume of air that can be expelled by the most powerful expiration, which is obviously the sum of the supplemental, breathing, and complemental air, is designated as the *vital capacity* —in all, 330 cubic inches.

139. *Ventilation.*—A knowledge of the respiratory process explains the great benefit to be derived from efficient ventilation. Ten thousand parts of ordinary atmospheric air contain from 2 to 4 parts of carbonic acid. If this gas be present to the extent of $1\frac{1}{2}$ to 3 parts in 1000, headache and giddiness are felt; and if it be increased to 20 parts in 1000, death will in all likelihood be the result. To secure a proper degree of dilution of carbonic acid in a small room, so as to render the air fit for respiration, about 2000 cubic feet of fresh air should be introduced every hour.

140. *Influence of Nervous System.*—The movements of respiration constitute an example of a complicated reflex action, the centre of which is in the *medulla oblongata*. The chief sensory nerves are the filaments of the pneumogastric, but the general sensory nerves distributed to the surface of the skin also act as afferent fibres. Thus we may excite a powerful inspiratory effort by dashing cold water on the face, or by a current of cold air directed on the

surface of the body. The motor or efferent fibres are those which Sir Charles Bell grouped together in his 'respiratory system.' The most important of these are the phrenics which supply the diaphragm, the intercostals, the facial, and the spinal accessory, which supplies motor filaments to the pneumogastric. The respiratory movements to a certain extent are under the control of the will. *Sighing, yawning, laughing, coughing, sneezing,* and *sobbing* are only modifications of the ordinary respiratory movements, excited either by mechanical irritation of the air-passages, as in coughing and sneezing, or by fatigue or mental emotions, as in the other instances.

THE NOURISHMENT OF THE TISSUES.

141. The various tissues of the body, such as muscle, bone, nerve, or brain, are nourished by the blood. But as this fluid is almost the same in chemical composition in different parts of the body, and as the tissues differ much in this respect from each other, we must adopt the theory that each tissue has an *elective power* in itself, whereby it selects from the blood exactly the material it requires for its growth. To secure healthy nutrition, we must have (1) *an adequate supply of blood.* If any part of the body be not supplied with abundance of blood, its actions are enfeebled ; and if the supply be cut off altogether, it soon weakens and dies. (2) *The blood must also be healthy in quality.* If affected by disease of any organ, so that certain injurious materials are not eliminated, the general nutrition of the body speedily suffers. To secure proper nutrition, a part must (3) *be subject to the influence of the nervous system.* Disease of the spinal cord causes paralysis of the lower limbs, and the muscles become soft, flabby, and diminish in size. Section of a nerve supplying a part is often followed by destruction of the part by ulceration. Finally (4), *the part itself must be in a healthy condition* to secure proper growth. Any tissue which has acquired any peculiarity of structure by previous disease, retains this peculiarity for many years ; but in course of time the tissue tends to revert to its original condition. This explains such phenomena as the perpetuation of cicatrices and the influence of the vaccine virus. In the latter case, the virus stamps a peculiar quality on the

blood and tissues, which modifies any subsequent attack of small-pox. *Growth* is dependent essentially on the supply of material to the tissues by the blood, and on the amount of waste of tissue. If the supply exceed the waste, as in childhood, the body increases in weight and power; if the supply and waste are equal, the body may remain in a stationary condition for many years, as in middle life; and if the supply be much less than the waste, the body loses weight and strength, as in old age.

SECRETION.

142. Secretion is that function by means of which certain fluids are separated from the blood for further service in the economy. Various of these secretions, such as the saliva, gastric juice, pancreatic juice, &c. have been already described, but here we may briefly refer to the process of secretion generally. However complicated the structure of the various secreting glands may be, it is found on minute

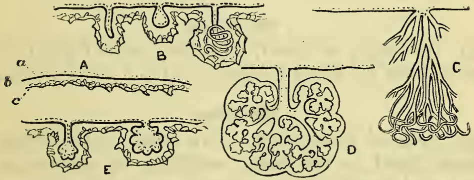

Fig. 79.—Diagram shewing various forms of Secreting Structures: A, general plan of a secreting membrane; *b*, basement membrane with cells, *a*, on one side, and blood-vessels, *c*, on the other; B, simple *tubular* (gastric glands), *follicular* (tonsils), and *elongated tubular* or *convoluted* glands (sweat glands); C, *compound tubular*, as in kidney; D, *compound racemose*, as in salivary gland, pancreas, &c.; E, *simple racemose*, two forms, as sebaceous glands, &c.

examination to consist of a delicate membrane, called a basement membrane, having blood-vessels richly distributed under its attached surface, and actively growing cells on its free surface. By foldings and reduplications of these elements of structure, all secreting glands are formed (fig. 79). The *cells*, however, are the active agents. They select from

the blood the materials necessary, and form the secretion. Recent researches have shewn that these cells are directly influenced by the nervous system (see p. 64). The secretion is found in their interior. They are developed, grow, live a certain time, drop off from the membrane, and becoming ruptured, the secretion is set free. Thus secretion is not opposed to growth, as at one time supposed: it is dependent on the *growth of certain cells.*

EXCRETION.

143. *General Characters of Excretion.*—During the vital activity of the tissues, new particles are assimilated by the process of growth already described. On the other hand, certain materials are worn out, and becoming soluble, partly pass into the blood. These effete matters must be removed from the blood, and cast out of the body, so that this important fluid may be kept in a healthy condition. This process of removal is the function of excretion. There are five great channels of excretion :

The Lungs.

144. The lungs, as already described under RESPIRATION, separate from the blood carbonic acid and watery vapour.

The Liver.

145. *General Description.*—This organ is the largest and heaviest gland in the body, weighing, on an average, 65 ounces avoirdupois. It is situated on the right side, beneath the lower ribs (fig. 25). It consists of five lobes, of a dark reddish colour, and these lobes are divided into lobules. The lobules are bound together by areolar tissue, and their structure is similar. The liver is supplied with the blood from which it derives its secretions by the portal vein (fig. 73, L), a vessel which collects all the blood circulating in the stomach, spleen, and intestines. The portal vein divides and subdivides in the liver, till it forms a plexus of minute vessels between and in the lobules, from which originate the radicles of the hepatic vein (fig. 73, *l*), a vessel which carries the blood from the liver to the ascending *vena cava.*

The connective tissue of the liver, and its vessels and nerves, are supplied by a special artery, the hepatic artery (fig. 73, *i*). The proper secreting structure of the liver consists of numerous compressed cells, about the $\frac{1}{1000}$th of an inch in diameter, called *hepatic cells* (fig. 80, *b*). These cells secrete materials from the blood, which they elaborate into bile. This secretion passes into minute ducts, the *hepatic ducts*, which originate in minute ducts between the cells, *a*. These ducts convey the bile out of the liver; and after it has become inspissated and mixed with mucus, from small mucous glands in the larger ducts, and from the gall-bladder (fig. 62, *g*), it is poured into the duodenum.

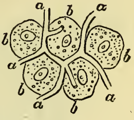

Fig. 80. — Hepatic cells, *b*; with the bile ducts originating amongst them, *a*.

146. *Functions of Liver.*—The liver performs at least three functions: first, the secretion of bile; second, the formation of fat; and third, the formation of animal starch or glycogen. The bile is to be regarded chiefly as an excretion rich in hydro-carbons, but during its passage from the economy, it performs certain functions referred to under DIGESTION (p. 74). It is highly probable that part of the bile is reabsorbed into the blood, but its ultimate function is unknown. The amount formed daily is about $3\frac{1}{2}$ pounds; but the quantity is liable to great variation.

147. *Glycogenic Function of the Liver.*—The formation of animal starch by the liver is called its *glycogenic function.* It is supposed that this starch, formed in the cells of the liver, is converted, by some kind of ferment existing in the blood of the hepatic vein, into sugar, which is carried to the lungs, where it is decomposed into carbonic acid and water. This, however, is a point not yet conclusively settled.

148. *Composition of the Bile.*—Bile is a neutral or slightly alkaline fluid. It contains (1) *mucus;* (2) *glycocholate* and *taurocholate* of soda; (3) *cholestrin,* held in solution by the bile salts; (4) products of the decomposition of *lecithin,* a substance which is one of the chief constituents of nervous tissue; (5) *urea;* (6) *colouring matters,* one of a reddish-yellow colour, *bilirubin;* and another of a green colour, *biliverdin;* (7) *fatty matter;* and (8) a *sugar-forming ferment.*

The Skin.

149. *General Description.*—This organ, continuous at various points with the internal mucous surfaces, covers the whole body, and consists of two layers: first, a hard epithelium, composed of cells more or less flattened, called the *epidermis* (fig. 81, *a*); and second, of the *derma*, or *cutis vera*, or true skin, *b*, which is formed of connective and elastic tissue. Underneath the true skin we find a layer of fat, *c*. The surface of the true skin is raised into a series of papillæ, *b*, connected with the sense of touch. We find in the skin two kinds of glands. The *sudoriparous* or sweat glands consist of a tube, coiled into a ball at the deeper part, and communicating with the surface by a spiral duct (fig. 81, *d*). The *sebaceous* glands are small racemose glands, which usually open into the hair follicles (fig. 82, *d*, *d'*), and secrete an oily fluid for lubricating the hairs and surface of the skin.

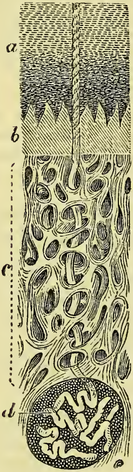

Fig. 81.—Vertical Section of the Skin of the Sole of the Foot: *a*, cuticle; *b*, papillæ; *c*, *cutis vera*, or true skin; *d*, sweat-gland imbedded deeply in the skin, and surrounded by fat. Its duct is seen passing to the surface. Magnified about 30 diameters.

150. *Secretions of Sweat.*—The chief excretion of skin is *sweat*, an acid watery fluid (having a small amount of salts, chiefly chloride of sodium, and a trace of organic matter, such as urea, in solution), which is usually carried off from the surface in the form of vapour. The amount varies greatly: from five pounds in the twenty-four hours, to one pound. That the separation of this excretion is important, is proved by the fact, that if the skin be varnished over, so as to prevent exhalation, death may

speedily ensue. All the various modifications of epidermis, such as hair, horn, nail, hoof, feathers, &c. may also be regarded in the light of excretions, but space compels us merely to allude to this fact.

151. *Functions of the Skin.*—The skin is (1) a protective covering for the parts underneath; (2) an organ of excretion; (3) an organ connected in certain parts especially with the sense of *touch;* and (4) partially as an absorptive and respiratory organ, absorbing small quantities of aqueous vapour, and giving off carbonic acid.

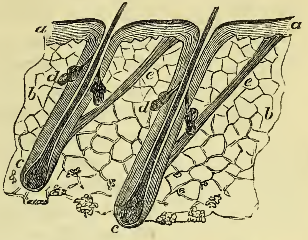

Fig. 82.—Vertical Section of Skin, shewing *a*, epidermis; *b*, true skin; *c*, *c*, hair bulbs; *d*, sebaceous glands opening into hair follicles; *e*, *e*, muscles for erecting the hairs.

The Kidneys.

152. *General Description.*—The human kidneys are situated in the loins, one on each side of the spine. A well-developed healthy kidney weighs about six ounces. When cut open (see fig. 83), we find a cavity communicating with the *ureter*, U, the excretory duct of the kidney, and we observe also that the organ consists of two substances, which are named, from their position, the external or *cortical*, and the internal or *medullary* substance. The medullary part consists of straight tubules, which divide in two as we pass outwards

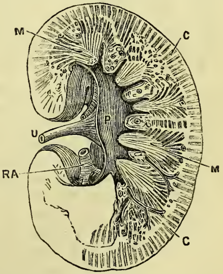

Fig. 83.—Longitudinal Section of Kidney: C, cortical substance; M, medullary substance; P, pelvis; U, ureter; RA, renal artery.

to the cortical part; while in the latter, the tubes are extremely convoluted. The tubules are termed *tubuli uriniferi*.

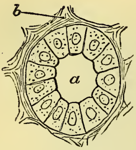

Fig. 84.—Section of a Uriniferous Tubule: *a*, section of tube; *b*, epithelial cells.

They are lined by irregularly shaped cells somewhat like those of columnar epithelium (fig. 84). In the cortical part of an injected kidney, there are numerous small round balls of capillaries called *Malpighian bodies*, after the celebrated anatomist who first observed them. In man they are about the $\frac{1}{100}$th of an inch in diameter. They consist of a mass of minute capillaries supplied with blood by an afferent vessel, and having also an efferent vessel to carry the blood away. Each of these little balls is embraced by the dilated end of one of the uriniferous tubes, as seen in fig. 85. It is generally believed that the watery part of the urine is here separated from the blood, while the solid matter is excreted by the action of the cells lining the tubules.

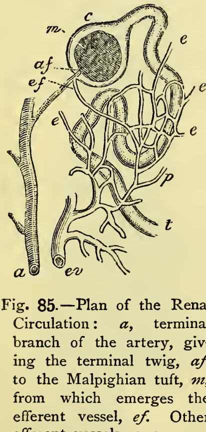

Fig. 85.—Plan of the Renal Circulation: *a*, terminal branch of the artery, giving the terminal twig, *af*, to the Malpighian tuft, *m*, from which emerges the efferent vessel, *ef*. Other efferent vessels, *e*, *e*, *e*, are seen proceeding from other tufts, and entering the capillaries surrounding the uriniferous tube, *t*. From this plexus of capillaries the emulgent vein, *ev*, springs.

153. *Functions of the Kidney.*—The function of the kidney is to excrete urine, a fluid rich in nitrogenous materials. The *urine* is an amber-coloured liquid, having a specific gravity of 1020, a slightly acid reaction, a saltish taste, and an odour peculiar to itself. The chief substance in the urine of man is *urea*, of which about an ounce is excreted daily, while during the same time about eight grains of uric acid are separated. In reptiles, the amount of urea is small, while *uric acid* is largely present. These substances are chiefly derived from the waste of the nitrogenous tissues, uric acid being

formed before urea. In rapid-breathing, warm-blooded animals, uric acid is rapidly oxidised to urea, and consequently only a small amount of the acid appears in the urine; whereas, in slow-breathing, cold-blooded animals, the oxidation is incomplete. Man being omnivorous, partakes of enough of food rich in carbon to prevent the complete oxidation, and therefore a small amount of uric acid is always found in his urine. The kidneys also separate inorganic matters, such as chlorides, sulphates, phosphates, &c. These, as well as the urea, are much modified as to amount by the nature of the diet, and the amount of fluid taken with them.

154. *Special Characters of the Urinary Secretion.*—Urine is a clear, amber-coloured, faintly acid fluid, with a bitterish taste, and an aromatic odour. It contains (1) water; (2) a small amount of mucus from passages; (3) urea, from the oxidation of nitrogenous matter; (4) uric acid, in the form of urates of soda and potash; (5) a number of less oxidised bodies in small quantities, such as allantoin, xanthin, creatin, creatinin, &c.; (6) colouring matter; (7) odoriferous matter; (8) salts, chiefly chlorides of sodium and potassium, sulphates of soda and potash, phosphates of soda and potash, phosphate of lime, and phosphate of magnesia; (9) a trace of sugar; and (10) small quantities of the gases oxygen, carbonic acid, and nitrogen. In flesh-eating animals, urea is present in large amount; very little uric acid being found; but in the urine of vegetable feeders, little urea and no uric acid are present, while *hippuric* acid exists in large amount.

155. *Conditions influencing the amount of Urine.*—The normal amount is from 50 to 60 ounces daily. It is less in summer than in winter. The amount seems to depend (1) on the intensity of the pressure of the blood within the Malpighian tufts; and (2) on the quantity of water or other diffusible matter taken into the system.

156. *Separation and Discharge of the Urine.*—The urine is constantly being secreted by the kidney. It is carried away to the bladder by a tube called the *ureter*—the bladder serving as a reservoir. It collects in the bladder until that organ is completely filled, when it is voided by contraction of the walls of the bladder, aided by the abdominal muscles. The evacuation is partly voluntary and partly involuntary.

The Intestines.

157. The excretions from the bowel consist not only of the non-nutritious materials of food, bile, mucus, and mineral matters, but also of fetid effete matters removed from the system by the lower bowel (see p. 76).

158. We have now concluded a description of the great function of nutrition, consisting, as will have been seen, of many stages, or processes, on the due performance of which the well-being of the body depends. All of these processes are intimately connected with the nervous system, which apparently presides over and regulates all.

THE FUNCTION OF INNERVATION.

159. *General Description of Nervous System.*—The vital processes included under the function of nutrition belong to the class of functions known as *vegetative*, because certain of them are common to vegetables as well as to animals. These functions have as their object the preservation of the plant. The animal has, however, another set of organs, by the use of which it becomes conscious of a world external to itself, and by which, as stated above, a control, both stimulating and regulative, is exercised over the other organs. By means of certain functions, which, from their occurrence in animals only, are termed *animal*, all the higher animals, and especially man, are endowed with sensation, motion, and volition. These powers are due to the presence of a nervous system, including two sets of nerves and nerve-centres—namely, the *cerebro-spinal system* and the *sympathetic system.*

The former consists of the *cerebro-spinal axis*, composed of the brain and spinal cord, and the *cerebral* and *spinal nerves* connected with this axis; while the latter consists chiefly of a double chain of *ganglia* or nervous masses, lying at the sides of the spinal column, and united with one another and with the spinal nerves by connecting threads of nervous substance.

160. *Characters of Nervous Matter to the Naked Eye.*—Nerve matter is of two kinds, *white* and *gray*, and may be readily seen by cutting through the brain of a sheep or of any other animal, when it will be observed that there is an outer layer of gray matter, while the interior is white. In the spinal cord these relations are reversed, the gray matter lying in the centre.

161. *Structure of Nerves.*—These consist of a number of delicate fibres, each of which is transparent as glass when examined in a perfectly fresh state, but usually seen with two well-defined lines on each side of a broad clear space. The central part is called the *axis cylinder*, and the outer part, the *white substance of Schwann.* Very minute nerve-tubes, as from those obtained near the surface of the brain (fig. 86, *e*, *f*), shew no white substance. The nerve-tubes vary much

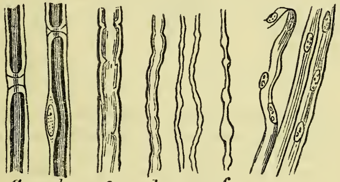

Fig. 86.—Nerves: *c*, ordinary-sized nerve-tube, shewing axis cylinder surrounded by white substance; *d*, smaller nerve-tube, with white substance scarcely visible; *e*, still smaller, with no white substance visible; *f*, varicose nerve-tube, from gray matter near surface of brain; *a*, nerve-tube, coloured by *perosmic* acid, shewing one of the *nodes of Ranvier*, or complete interruption of the axis cylinder; *b*, nerve-tube shewing nucleus and node of Ranvier (the axis cylinder is blackened by the action of the perosmic acid); *g*, non-medullated nerve-tubes from sympathetic, having no white substance, and nucleated at intervals.

in diameter. Those of the *sympathetic* have no white substance. Recently it has been shewn that at certain distances the axis cylinder is interrupted, constituting the so-called *nodes* of *Ranvier.* During life, the substance in the interior of the sheath of the nerve-tube (the *neurilemma*) is in a semi-fluid state, and the conception of a nerve-tube to be formed is, a thin cylinder (*neurilemma*) inclosing a

cylinder of semi-fluid substance (*white substance of Schwann*), within which there is a *core* of semi-fluid matter, of different consistence from the last, called the *axis cylinder.*

162. *Nerve-cells.*—When the nerves are traced into the nerve centres, they are found to terminate in *nerve-cells*, which are of various forms. These cells are composed of protoplasmic matter, slightly molecular, and usually having issuing from them one or more *poles* or processes,

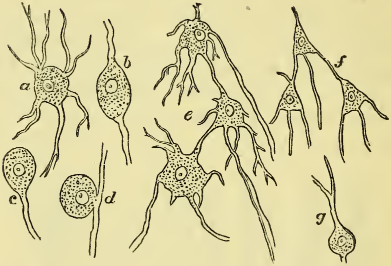

Fig. 87.—Various forms of Nerve-cells: *a, multipolar*, from gray matter of spinal cord; *b, d, bipolar*, from ganglia on posterior roots of spinal nerves; *c, g, unipolar*, from cerebellum; *g* shews indications of a process coming off at lower end; *e*, union of three multipolar cells in spinal cord; *f*, union of three *tripolar* cells in gray matter of cerebral hemispheres.

which are believed to be in continuation with the axis cylinders of nerve-tubes. They vary in size from the $\frac{1}{5000}$th to the $\frac{1}{400}$th of an inch. The function of these cells is to receive or transmit nervous influences, but how they do so is quite unknown. Gray matter is composed chiefly of these cells lying amongst extremely delicate connective tissue termed *neuroglia.*

163. *Functions of a Nerve-tube.*—The function of the nerve-tube is to receive an impression of any kind, mechanical, chemical, thermal, or volitional, thereupon to generate an influence, and to conduct this influence to or from a nerve-centre. When examined by a galvanometer in the manner described with reference to muscle (see p. 45), the surface is found to be *positive* to the transverse section;

and during the action of a nerve-tube, this electric current diminishes in amount—that is, there is a *negative variation*, as in the case of muscle. When a continuous current of electricity is passed along a nerve, it passes into a peculiar condition, termed the *electrotonic state*, a knowledge of which, however, is not of great practical importance. The rapidity of the nerve-current is, in cold-blooded animals, from 75 to 120 feet per second; incomparably slower than light or electricity. In warm-blooded animals, such as man, it probably travels at a rate of about 200 feet per second.

THE DEVELOPMENT OF THE NERVOUS SYSTEM IN THE ANIMAL KINGDOM.

164. Nothing conducts sooner to an intelligent comprehension of the complicated nervous system of man and of the higher animals than the study of the gradual development of the nervous system throughout the animal kingdom, from its simpler to its more complex forms.

165. *Nervous System of Invertebrates.*—In none of the *Protozoa*, including such animals as sponges, infusoria, &c. has any trace of a nervous system been discovered. Neither is any rudiment of it to be found in the *Hydrozoa*, the first subdivision of the cœlenterate

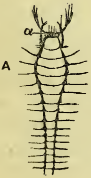

Fig. 88.—Nervous system of a *Serpula* or Sea-worm: *a*, cephalic ganglion.

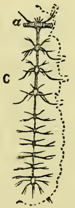

Fig. 89.—Nervous system of an Ant: *a*, cephalic ganglion.

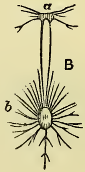

Fig. 90.—Nervous system of a Crab: *a*, cephalic ganglion; *b*, mass of ventral ganglia fused together.

group of animals; but in the *Actinozoa*, which comprehends such animals as the sea-anemone, it is first discovered as a little knot or nodule of nervous matter, from which delicate fibres radiate. Such a nodule is called a *ganglion*, and the filaments constitute *nerves*.

Among the *Echinodermata*, such as star-fishes, sea-urchins, &c., we find the nervous system consisting of a number of ganglia, connected together, so as to form a ring, or *nervous circle*, from which nerve filaments pass to various parts of the body. In some of the *Annelidæ*, or worms, we find (fig. 88) a ganglion, *a*, in the neighbourhood of the head, from which two nervous cords pass along the ventral (or belly) surface of the animal. In the *Mollusca*, or shell-fish, there are usually at least three ganglia with radiating nerves—one in the head, one in the foot, and one posterior and above the alimentary canal. In the *Insecta*, or insects (fig. 89), we find a large ganglion in the head *a*, from which a double cord passes backward along the *ventral* surface of the animal, and in connection with which there are three or more ganglia, as seen in the figure. In the *Crustacea*, such as the common crab (fig. 90), there is a large ganglion near the anterior extremity, with nerves for the eyes and antennæ, *a*, while behind we find the ventral chain of ganglia fused into one mass, *b*.

166. *Nervous System of Vertebrates.*—All of the groups now mentioned belong to the invertebrate subdivision of the animal kingdom, and all have their nervous system along the *ventral* aspect of the body. We now come to the vertebrate subdivision, or those having a backbone, and here we meet with another nervous system extending along the *dorsal* aspect of the animal, to which anatomists have given the name of the *cerebro-spinal system.* This consists of a chain of ganglia constituting the *brain*, behind which there is an elongated mass of nervous matter running from the brain through the canal of the vertebral column, and called the *spinal cord*, or *spinal marrow.* In all vertebrate animals, the spinal marrow seems to be much alike in general structure and arrangements, but one animal differs from another (as a fish from a frog, or a pigeon from a rabbit) by the degree of development of the brain. The brain consists of a series of ganglia which, in a typical or ideal brain, might be thus represented (fig. 91). These ganglia, from before backwards, are: 1, olfactory bulbs; 2, cerebral lobes; 3, corpora striata; 4, optic thalami; 5, cerebellum; 6, pons

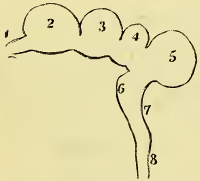

Fig. 91.—Diagram of an ideal or typical Brain: 1, olfactory lobes; 2, cerebrum; 3, corpus striatum; 4, optic thalamus; 5, cerebellum; 6, pons Varolii; 7, medulla oblongata; 8, spinal cord.

Varolii; 7, medulla oblongata; and 8, spinal cord. Between 4 and 5, we also find a mass of nervous matter termed the optic lobe or lobes.

Such a brain is seen, for example, in many *fishes* (fig. 92), where

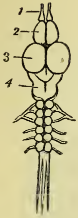

Fig. 92.—Brain of Common Gurnard: 1, olfactory; 2, cerebral lobes; 3, corpora striata; 4, cerebellum.

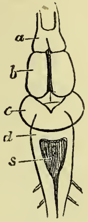

Fig. 93.—Brain of Common Frog: *a*, olfactory; *b*, cerebral lobes covering corpora striata; *c*, corpora quadrigemina, or optic lobes; *d*, cerebellum (rudimentary); *s*, back of medulla shewing fossa.

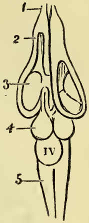

Fig. 94.—Brain of Tortoise: 1, olfactory; 2, cerebral lobes; 3, corpora striata; 4, optic lobes; IV, cerebellum; 5, medulla. Part of the surface of the cerebral lobes has been removed to shew the cavities in the interior termed the *ventricles*.

the cerebral hemispheres, 2, are still of very small size, and do not overlap any of the adjacent structures. The same arrangement may also be studied in the brain of *amphibians*, such as the common frog (fig. 93); but here we find the cerebral lobes larger, so that they now extend backwards so as to cover the *corpora striata*. When we ascend to *reptiles*, such as the tortoise (fig. 94), we find the cerebral hemispheres larger, broader, and thicker as regards the amount of gray nervous matter on the surface. The cerebellum (IV) is still feebly developed. In the brains of the bird the cerebral lobes are still further developed

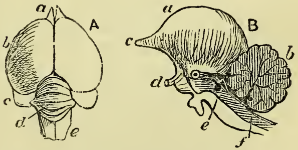

Fig. 95.—Brain of Pigeon: A, view from above. B, lateral view of a bisected brain. A—*a*, olfactory; *b*, cerebral lobes; *c*, optic lobes; *d*, cerebellum; *e*, medulla. B—*a*, cerebrum; *b*, cerebellum; *c*, olfactory; *d*, optic nerves; *e*, medulla; *f*, cord.

(fig. 95), and the cerebellum has become so large as to wedge in between the two optic lobes and push these towards the base of the brain. The mammalian brain shews the hemispheres of the cerebrum still larger, so that they now project so far posteriorly as to cover not only the corpora striata and optic thalami, but also the optic lobes. The cerebellum is also much more highly developed. The brains of the lower mammals, such as the rabbit (fig. 96), are nearly smooth on the surface, and exhibit only a trace of those elevations and depressions which we meet with on the surface of the brains of

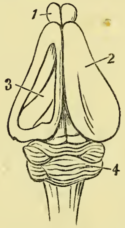

Fig. 96.—Brain of Rabbit: 1, olfactory; 2, surface of cerebral hemisphere; 3, cavity in brain called a *ventricle*, in the floor of which is seen the *corpus striatum;* 4, cerebellum.

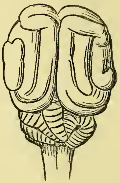

Fig. 97.—Brain of Common Cat, shewing convoluted surface.

such an animal as the common cat (fig. 97), where we find the surface distinctly convoluted. The *convolutions* increase in number, depth, and complexity as the intelligence of the animal increases, until we come to the brain of man, where in a well-developed brain we find them presenting the appearance depicted in fig. 98. It will thus be seen that as we ascend from the lower to the higher vertebrates, the brain becomes more and more complex in structure, chiefly by the great growth and development backwards of the cerebral hemispheres, and by the appearance of convolutions on the surface of these, indicating increase of gray matter.

THE HUMAN BRAIN.

167. *General Description.*—The brain consists of the *cerebrum*, or brain proper, which occupies the whole of the upper and front parts of the cavity of the skull; the *cerebellum*, or little brain, lying beneath the hinder part of the cerebrum;

and the *medulla oblongata*, or oblong marrow, which may be regarded as a continuation of the spinal cord within the

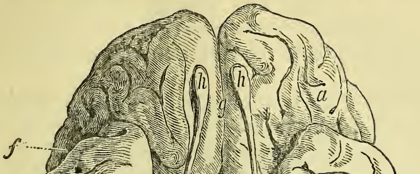

Fig. 98.—Human Adult Brain: *a*, anterior lobe of cerebrum; *b*, middle lobe; *c*, posterior lobe of cerebrum, appearing behind; *d*, cerebellar hemisphere; *e*, medulla oblongata; *f*, fissure of Sylvius; *g*, longitudinal fissure; *h*, *h*, olfactory bulbs; *i*, optic commissure—the optic nerves are seen interchanging fibres; *l*, three roots of olfactory process; *m*, white round bodies (*corpora albicantia*), the terminations of the anterior portions of fornix; *n*, where the vessels perforate the brain substance, hence called posterior perforated space; *o*, third pair of nerves coming to supply muscles of the eyeball, from *p*, the crus cerebri; *q*, fourth nerve, turning round from the valve of Vieussens; *r*, fifth pair; *s*, pons Varolii; *t*, sixth pair of nerves; *u*, seventh pair, portio dura for muscles of face, and portio mollis for hearing; *v*, posterior pyramids of cerebellum, seen to interchange fibres; *w*, and two below, are eighth pair—namely, glosso-pharyngeal, vagus or pneumogastric, and spinal accessory nerve; between *w* and *v* is the small prominence called olivary body; *x*, *y*, two roots of ninth pair of nerves, motor nerve of tongue.

cavity of the cranium, and as forming the connection between the brain and cord. The cerebrum and cerebellum are

almost completely bisected into two lateral halves by a deep longitudinal fissure; and the surface of the former is divided by a considerable number of tortuous furrows, nearly an inch deep, into *convolutions*. As the gray matter is extended into these furrows, its quantity is thus vastly increased.

At the base of the cerebrum, and connected with it, there are two large ganglionic masses of gray and white matter, called the *corpora striata*; behind these, other two bodies of a similar nature, the *optic thalami*; and still farther back, four bodies, two on each side, the *corpora quadrigemina*. All these parts of the brain are connected with each other by numerous nerve fibres. The fibres from the spinal cord pass upwards in the medulla oblongata; those from the posterior part of the cord going chiefly to the cerebellum, while those from the anterior pass chiefly to the cerebrum. In the cerebrum, cerebellum, and ganglia, we also find fibres running from their anterior to their posterior ends, while other fibres run transversely, and unite corresponding parts on opposite sides of the brain. Thus there is evidently community of function.

168. *Functions of different parts of the Brain.*—The functions of these different parts may be briefly stated to be as follows: (1) the *cerebrum* is the seat of sensation, volition, emotion, and of those intellectual powers which constitute MIND; (2) the *cerebellum* is probably the regulator of muscular movements; (3) the *corpora striata* are great centres of voluntary movement, not of volition, but of the nervous mechanism by which, when we will with the cerebrum, the influences are sent along the spinal cord to the various muscles; (4) the *optic thalami* perform a similar function of collecting and transmitting impressions with regard to sensation; (5) the *corpora quadrigemina* receive impressions by the optic nerves from the eyes, and transmit these to the cerebrum, where there is then the consciousness of sight; and (6) the *medulla oblongata*, and an adjoining part called the *pons Varolii*, are the seat of the nervous influences which regulate swallowing, breathing, and other important involuntary movements. The parts of the brain last mentioned

(6) are absolutely essential to life. The other parts may be cut or mutilated without instant death, but this quickly follows injury to the medulla.

Recent observations have been made on the cerebral hemispheres by stimulating small areas on their surface by feeble electric currents, the chief results of which are the discovery of certain centres in the convolutions which, when stimulated, cause movements of definite groups of muscles. These centres have been termed *psycho-motor* centres ; but while the facts are undeniable, it is doubtful how far they may be accounted for by the diffusion of electrical currents to deeper centres.

169. *Functions of Nerves.*—Nerves have different functions. When an influence travels along a nerve to a muscle, it excites the muscle to contract, and the former is then called a *motor* nerve ; when it travels to the brain and causes a sensation, we call such a nerve *sensory.* A third class of nerves, when stimulated, convey an impression to a gland, and the consequence is *secretion.* There is no evidence that there is any difference of structure between motor and sensory nerves. The difference of *result* on stimulating a nerve depends on its mode of termination. For example, if it terminate in the hemispheres of the brain, pain is probably felt ; if in a muscle, the result is contraction ; if in a gland, the secretion is augmented or diminished ; if in a blood-vessel, the vessel will contract. Most nerves contain both sensory and motor tubes. Some are purely sensory, as certain parts of the fifth cranial nerve ; others purely motor, as the facial, or seventh cranial nerve ; while all the spinal nerves are senso-motory. Certain nerves respond only to particular stimuli. For example, the optic nerve is affected only by vibrations of rays of light, acting in the first instance on a special terminal apparatus called the *retina.* Such are called *special sensory* nerves, and include those of sight, hearing, taste, smell. The nerves of touch are those of common sensibility distributed to the skin.

170. *Cranial and Spinal Nerves.*—Twelve pairs of nerves are given off from the brain, and thirty-one from the spinal cord. The spinal nerves are all *sensori-motor*—that is, they contain both kinds of filaments. The cranial nerves

may be thus classified, and their general origin may be studied in fig. 99 :

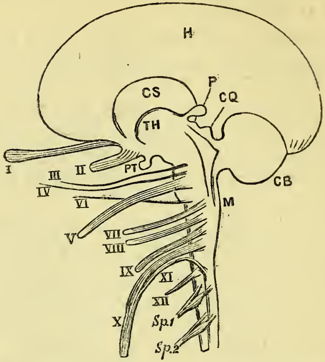

Fig. 99.—Diagram of the Brain, shewing origin of the cranial nerves: H, hemispheres; CS, corpora striata; P, pineal gland; CQ, corpora quadrigemina; TH, optic thalami; PT, pituitary body; M, medulla. The Roman numerals indicate the nerves. *Sp.* 1, *Sp.* 2, first and second spinal nerves. Observe the ganglia on the posterior roots.

Order.	Anatomical Name.	Physiological Name.	Function.
1st Pair...	Olfactory, I...	Olfactory.....	Special sense, smell.
2d Pair...	Optic, II......	Optic	Special sense, sight.
3d Pair...	Motor-oculi, III.	Motor-oculi..	Motor, for all the muscles of the eyeball except *two*, IV. and VI.
4th Pair...	Trochlear, IV.	Pathetic......	Motor for superior oblique muscle of eyeball.
5th Pair...	Trigeminal, or Trifacial, V.	5th Nerve...	Sensori-motor—*sensory* to face, mouth, and part of tongue; *motor* to muscles of mastication.
6th Pair...	Abducens, VI.	6th Nerve...	Motor to external rectus muscle of eyeball.
7th Pair	Portio dura, Portio mollis, VII., VIII.	Facial .... Auditory,	Two portions—*facial*, the motor nerve of the face; and the *auditory* — special sense of hearing.

8th Pair	8th	8th	Three distinct nerves: (1) The *glosso-pharyngeal*, IX., special sense of taste; (2) the *spinal accessory*, XI., motor to trapezius muscle in back, sterno-cleido-mastoid muscle in neck, and motor filaments to pneumogastric; (3) the *pneumogastric or vagus*, X., which extends through the cavity of the chest to the upper part of the abdomen—sensory and motor to pharynx, œsophagus, larynx, lungs, heart, and stomach; inhibitory to heart; *depressor* to vaso-motor centre in the medulla.
9th Pair	Hypoglossal,	Hypoglossal, XII.	Motor to muscles of tongue.

THE SPINAL CORD.

171. The *spinal cord* or *marrow* is a cylindrical column of soft nervous tissue, extending from the base of the skull, where it is continuous with the *medulla oblongata*, to the region of the loins, where it tapers off to a thread in the lowest part of the vertebral canal. Its average length is eighteen inches. It is not only divided by two fissures in the middle, but each half is again divided longitudinally into three equal parts by two parallel series of nervous filaments, which are the anterior and posterior roots of the spinal nerves (fig. 100). The posterior root presents a swelling or ganglion, immediately beyond which the two coalesce into the trunk of a nerve which, after emerging through a hole called the intervertebral foramen, is distributed into branches to the parts it is destined to supply with nervous filaments; as, for example, the muscles of the trunk and limbs and the surface of the body. These roots have separate functions, the anterior being composed of motor, while the posterior contain sensory tubes. Hence if the anterior

root be divided, or if the column of the cord from which it springs be diseased, loss of *motion* in the part which it supplies is the result, while if the posterior root were similarly acted on, there would be loss of *sensibility*. The anterior columns of the medulla decussate (that is, send nerve-fibres across to the adjoining column); while many of the fibres of the posterior columns decussate all the way up the back of the cord. Consequently, injury to the right anterior column causes loss of motion on the same side, while injury to the right posterior column paralyses sensation as regards the opposite side of the body. The decussation of the anterior columns in the medulla also explains how a clot of blood in the right hemisphere of the brain, as in apoplexy, usually causes loss of motor-power on the left side of the body.

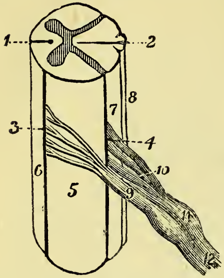

Fig. 100.—Side View of the Spinal Cord, shewing the Fissures and Columns: 1, anterior median fissure; 2, posterior median fissure; 3, anterior lateral fissure; 4, posterior lateral fissure; 5, lateral column; 6, anterior column; 7, posterior column; 8, posterior median column; 9, anterior root; 10, posterior root; and 11, ganglion of (12) a spinal nerve.—From Gray's *Human Anatomy*.

SYMPATHETIC SYSTEM OF NERVES.

172. This nervous system consists of a gangliated cord found on each side of the spinal column, and giving to and receiving numerous filaments from the cerebro-spinal system. Observation and experiment have shewn that it has the following functions: (1) it controls the contractions of all structures which contain involuntary muscular fibre, such as the viscera; (2) it governs the various secretions, probably by acting on the blood-vessels of the glands; and (3) it is *vaso-motor*, controlling the calibre of the blood-vessels, and thereby regulating the circulation in the capillaries and the amount of animal heat.

THE SPECIAL SENSES.

There are five senses—namely, *touch*, *taste*, *smell*, *sight*, and *hearing*.

Touch.

173. The sense of touch, including that of different degrees of heat, is possessed by the skin, by the walls of the mouth and nostrils, and by the tongue, but it is most highly developed on the tips of the fingers. The essential organs of this sense are the true skin, containing capillaries, and the terminations of sensory nerves. On examining the surface of the true skin by a magnifying-glass, we can see a regular arrangement of papillæ, or cone-like projections, about $\frac{1}{100}$th of an inch in length (fig. 81, p. 104). In many of these papillæ there are found small round or oval bodies made of hard fibrous tissue, and having a nerve-tube coiled round them, and sometimes penetrating into their interior. These are called *touch-bodies* (fig. 101). They serve as resisting structures against which the nerve may be pressed, and thus the sense of touch may be intensified. When one of those nerves is pressed by the contact of any foreign body, an influence is produced which travels to the brain, where we become conscious of the impression. This consciousness, however, we refer not to the brain, but to the part affected; a subjective power, which is probably the result of experience.

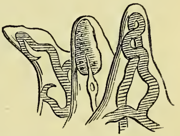

Fig. 101.—Three Papillæ of the Skin, the central one containing a *touch-corpuscle*.

Taste.

174. The organs of taste are in the mucous membrane of the tongue, especially at its back part. The nerves of taste are the lingual branch of the fifth cranial nerve and the glosso-pharyngeal, the former supplying the anterior two-thirds, and the latter the posterior one-third of the tongue. Various authorities also regard the *chorda tympani*, a branch of the facial, as a nerve of taste for the tip of the

tongue. The mucous membrane of the tongue presents papillæ of various forms, called *filiform*, or thread-like; *fungiform*, or mushroom-like; and *circumvallate*. The circumvallate papillæ are from thirteen to fifteen in number, and are set in the form of a V with its point backwards. Each resembles a broad fungiform papillæ surrounded by a trench. They are regarded as the essential organs of taste. Recently, flask-shaped bodies have been found in the tongue of the rabbit. They are seen in fig. 102. They derive their nerves

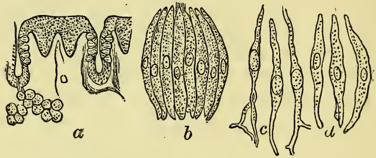

Fig. 102.—Organ of Taste from Tongue of Rabbit: *a*, section through *taste organ*, shewing flask-shaped bodies in the depressions; *b*, flask body isolated, shewing that it is made of spindle-shaped cells; *c*, small cells found in flask, having pointed lower ends which are continuous with nerve-fibres; *d*, fusiform cells which form wall of flask-shaped body.

chiefly from the glosso-pharyngeal nerve. The contact of a sapid body with the surface of the tongue is not sufficient to evoke the sense of taste. The substance must be dissolved, and to effect its solution a special fluid is provided—the saliva. In febrile diseases, in which the tongue is dry and coated, the sense of taste is either dormant or perverted. Taste is more acute in some persons than in others. It is sometimes blended in a remarkable way with smell, giving rise to the peculiar sensation we call *flavour*. The sensations produced by the contact of mustard, pepper, &c. with the tongue are not those of taste, but rather exaggerated forms of touch.

Smell.

175. The organ of the sense of smell is the mucous membrane lining a part of the nasal cavities supplied with nerves from the *olfactory* bulbs or first pair of cranial nerves. Attached to the side walls of each nasal cavity are two delicate scroll-like bones, called *turbinated bones*, which to a great

extent divide each cavity into three spaces, lying one above the other. The uppermost two of these constitute the true olfactory chambers, while the lowest passage is merely used for respiratory purposes. The whole of this bony framework is covered by moist mucous membrane, having imbedded in it flat elongated cells attached to the ramifications of the olfactory nerves (fig. 103). By the contact of certain substances with these, a sensation of smell is produced. According to Graham, 'all odorous substances are in general such as can be readily acted on by oxygen.' Animal effluvia keep near the soil, hence the bloodhound runs with his nose to the ground. The sense of smell is extremely delicate in most individuals. It is soon blunted, and consequently many who live among disagreeable odours do not perceive them. A distinction must be drawn between a smell proper, like that of a violet, and the irritation produced by the fumes of ammonia. The close stuffy sensation experienced on entering an ill-ventilated crowded apartment, is due chiefly to interference with the free play of respiration.

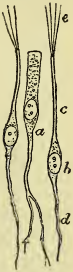

Fig. 103.—Cells from the olfactory organ, of two kinds—*a*, with broad ends like knife-handles; *c*, with delicate pointed ends, and continuous with nerve-tube at *d*.

Sight or Vision.

176. The sensation of light results from the influence produced indirectly on the expansion of the filaments of the optic nerve by vibrations of a delicate and subtle substance known as 'ether.' But the falling of light upon the optic nerve itself will produce no sensation. An intermediary apparatus is necessary—the *retina*, which is an expansion of nervous matter placed behind the optic nerve. It is now known that the action of light on the retina is something similar to that produced on a photographic surface, and that it is associated with a change in the normal electrical condition of the retina.

177. *General Description of Eye.*—The *globe of the eye* is placed in the anterior part of the orbit, in which it is held

in position by its connection with the optic nerve posteriorly, and with the muscles which surround it, and by the eyelids in front. It is further supported behind and on the sides by a quantity of fat. The eyeball is composed of several investing membranes, and of certain transparent structures, which are inclosed within them. These transparent structures act as refractive media of different densities, so that rays of light entering the eye are so bent as to come to

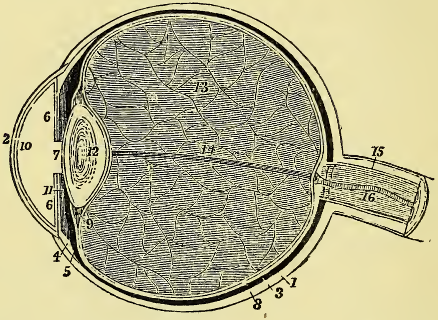

Fig. 104.—A Longitudinal Section of the Coats of the Eye: 1, the sclerotic, thicker behind than in front; 2, the cornea; 3, the choroid; 6, the iris; 7, the pupil; 8, the retina; 10, the anterior chamber of the eye; 11, the posterior chamber; 12, the crystalline lens, inclosed in its capsule; 13, the vitreous humour, inclosed in the hyaloid membrane, and in cells formed in its interior by that membrane; 15, the sheath; and 16, the interior of the optic nerve, in the centre of which is a small artery.

a focus on the retina. Thus a distinct image is formed. These refractive structures are, from before backwards—1st, the cornea, a transparent epidermic structure (fig. 104, 2); 2d, the aqueous humour in the anterior chamber, 10; 3d, the lens, composed of numerous laminæ, like the folds of an onion, 12; and lastly, the vitreous humour, a jelly-like structure, 13.

178. The outermost coat of the eye is the *sclerotic*, 1 (from *skleros*, hard). It is a strong, dense, white, fibrous structure. Posteriorly, it is perforated by the optic nerve. This coat, by its great strength and comparatively unyielding

structure, maintains the inclosed parts in their proper form, and serves to protect them from external injuries.

179. The *choroid coat*, 3, is a dark-coloured vascular membrane, containing pigment cells (see fig. 37, p. 38). In front, it ends by means of the *ciliary processes*, which consist of about sixty or seventy radiating folds. These fit into depressions in the suspensory ligament of the lens, and assist in keeping it in its proper position.

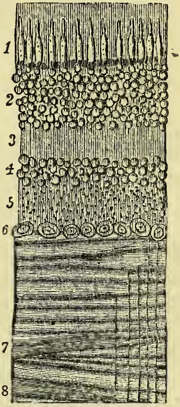

Fig. 105.—A Vertical Section of the Human Retina: 1, the layer of rods and cones (Jacob's membrane) next the choroid coat; 2, the external granular layer; 3, the intervening layer between 2 and 4, the internal granular layer; 5, finer granular layer; 6, layer of nerve-cells; 7, fibres of the optic nerve; 8, limitary membrane next the vitreous humour.

180. The *iris* may be regarded as a process of the choroid, with which it is continuous. It is a thin flat curtain, hanging vertically in the aqueous humour in front of the lens, and perforated by the pupil for the transmission of light. It is composed of unstriped muscular fibres, one set of which being arranged circularly round the pupil, and, when necessary, effecting its contraction; while another set lie in a radiating direction from within outwards, and by their action dilate the pupil. Thus more or less light may be admitted into the eye, and the function of the iris is like that of the diaphragm in many optical instruments.

181. The varieties of colour in the eyes of different individuals and of different kinds of animals mainly depend upon the colour of the pigment, which is deposited in cells in the substance of the iris.

182. Within the choroid is the *retina* (fig. 105). With the naked eye it is seen to be a delicate semi-transparent sheet of nervous matter, lying immediately behind the vitreous humour, and extending from the entrance of the optic nerve nearly as far as the lens. On examining the

retina at the back of the eye by an instrument called an *ophthalmoscope*, we observe, directly in a line with the axis of the globe, a circular yellow spot called, after its discoverer, the *yellow spot* of Sömmering. The only mammals in which it exists are man and the monkey. It is the point of distinct vision. When we read a book, we run the eye along the lines so as to bring portions of the line successively on the yellow spot. If, on the other hand, we carefully fix our attention on a word in the middle of the line, we see that word distinctly, because it is on the yellow spot, while the words towards each end of the line are less distinct, being on other and less sensitive portions of the retina.

183. The structure of the retina, as revealed by the microscope, is seen in fig. **105**. It is now well known that the part really affected by light is the layer of rods and cones next the choroid, so that a ray of light passes through all the other layers ere it reaches this sensitive layer. Each rod or cone is probably in direct communication with a filament of the optic nerve, so that, when excited by light, an influence is transmitted along this filament to the brain, and the consequence is a luminous impression.

184. The *transparent media* through which rays of light must pass before they form on the retina the images of external objects are:

185. Immediately behind the transparent cornea is the *aqueous humour*, which fills up the chamber between the cornea and the lens. It is nearly pure water, with a trace of chloride of sodium.

186. The *crystalline lens* lies opposite to and behind the pupil, close to the iris, and its posterior surface is received into a depression on the forepart of the vitreous humour (fig. **104**). In form, it is a double convex lens, with surfaces of unequal curvature, the posterior being the most convex, and the curvature is also less at the centre than towards the margin.

187. The *vitreous humour* lies in the concavity of the retina, and occupies about four-fifths of the eye posteriorly.

188. The appendages of the eye are:

The *muscles* by which the eye is moved are four

straight (or *recti*) muscles, and two oblique (the superior and inferior). By the duly associated action of these muscles, the eye is enabled to move through a considerable range without moving the head.

The *eyelids* are two thin movable folds placed in front of the eye, to shield it from too strong light, and to protect its anterior surface. The eyelashes intercept the entrance of foreign particles directed against the eye, and assist in shading that organ from an excess of light.

The *lachrymal apparatus* consists of the lachrymal gland, by which the tears are secreted; two canals, into which the tears are received near the inner angle of the eye; the sac, into which these canals open; and the duct, through which the tears pass from the sac into the nose. The constant motion of the upper eyelid induces a continuous gentle current of tears over the surface, which carry away any foreign particle that may have been deposited on it.

189. *Mechanism of Vision.*—The various uses of the different structures of the eye are readily understood. Assuming a general knowledge of the ordinary laws of geometrical optics, we will trace the course of the rays of light proceeding from any luminous body through the different media on which they impinge. If a luminous object, as, for example, a lighted candle, be placed at about the ordinary distance of distinct vision (about ten inches) from the front of the eye, some rays fall on the sclerotic, and being reflected, take no part in vision; the more central ones fall upon the cornea, and of these some also are reflected, giving to the surface of the eye its beautiful glistening appearance; while others pass through it, are converged by it, and enter the aqueous humour, which probably also slightly converges them. Those which fall on and pass through the outer or circumferential part of the cornea are stopped by the iris, and are either reflected or absorbed by it; while those which fall upon its more central part pass through the pupil. The rays now impinge upon the lens, which, by the convexity of its surface, and by its greater density towards the centre, very much increases

the convergence of the rays passing through it. They then traverse the vitreous humour, the principal use of which appears to be to afford support to the expanded retina, and are brought to a focus upon that tunic, forming there an exact, but inverted image of the object.

190. *Accommodation of the Eye to Distance.*—It will be found on experiment that we cannot see a distant and a near object at the same moment. For example, if we look through a railing at a distant church spire, and fix our attention on the spire, we do not distinctly see the railing; and *vice versâ*. This was early observed; but, until recently, the mechanism by which the eye accommodates or focuses itself for different distances was unknown. Cramer was the first to point out that if we bring a candle-flame near the eye in a dark room, we may see three images—1st, an erect image reflected on the cornea; 2d, an erect image on the anterior surface of the lens; and 3d, an inverted and very faint image on the posterior surface of the lens. He also shewed that when the eye looks quickly at a near object, after having been for some time directed to a distant one, the middle image moves forward nearer to the first, and also becomes smaller, shewing that for near vision the anterior surface of the lens becomes more convex. Helmholtz afterwards, by means of an instrument called the *ophthalmometer*, measured the sizes of those reflections, when observed at near and far distances, and, from certain data, calculated by mathematical formulæ the radii of curvature of the reflecting surfaces. Thus he shewed conclusively that the accommodation of the eye for different distances is effected by changes in the curvature of the anterior surface of the lens. The physiological explanation is as follows:

The lens, which is elastic, is kept habitually in a state of tension by the pressure of the suspensory ligament, and consequently has a flatter form than it would take if left to itself. The ciliary muscle contracts, by a reflex mechanism, not thoroughly understood, when we look at a *near* object. By contracting, it relaxes the ligament, and thereby diminishes its elastic tension upon the lens. The anterior surface of the lens, consequently, becomes more convex, and thus the divergent rays from a near object are brought to a focus on the retina. The lens returns to its former shape when the ciliary muscle ceases to contract.

191. *Defects of Vision.*—It has been shewn that the human eye is not a perfect optical instrument in the sense of being accurately

corrected for *spherical* and *chromatic* aberration, but it is so nearly perfect in this respect that the defect escapes our notice unless looked for with special appliances, and consequently we suffer no practical inconvenience. In some people there is a defect called *astigmatism*, in which the individual cannot see at the same distance, and in the same plane, a horizontal and vertical line with equal distinctness. It is due to differences in the vertical and horizontal meridians of the cornea or lens. There are two common forms of defective vision, however, which require notice—namely, short-sightedness or *myopia*, and long-sightedness or *presbyopia*. They are due to an abnormality either in the curves or in the density of the refracting media, or in the length of the horizontal axis of the eyeball. In *short-sightedness* from too great a refractive power from either cause, the rays from objects at the ordinary range of distinct vision are brought too soon to a focus, so as to cross one another, and to diverge before they fall on the retina; the eye in this case being able to bring to the proper focus on the retina only those rays which were previously diverging at a large angle from a very near object. The correction for this deficiency is accomplished by interposing between the eye and indistinctly seen objects a *concave* lens, with a curvature sufficient to throw the images of external objects at the ordinary distance of distinct vision backwards upon the retina. In *long-sightedness*, on the other hand, there is an abnormal diminution of the refractive power, so that the focus is behind the retina. This defect is corrected by a *convex* lens, which increases the convergence of the rays of light.

192. *Subjective Phenomena of Vision.*—When small particles of matter occur in the aqueous or vitreous humour, they cast shadows on the retina which appear to float in the air before the eye, often like small black dots, but sometimes assuming grotesque forms. These are called *muscæ volitantes*. They are often seen during ill health, more especially if associated with bilious disorder. Another series of phenomena are produced by pressure on the eyeball, either continuous, or sudden as by a blow. Then a number of rings of various colours, or a flash of light, may be observed. These are termed *phosgenes*, and are due to mechanical irritation of the retina. Finally, if we fix the attention for a minute or two on a coloured surface, say a red wafer, brilliantly illuminated on a white ground, and then transfer the gaze to another part of the room, or shut the eyes, in a second or two a huge wafer, of a colour complementary to the one at first looked on, say blue, makes its appearance, and floats before us. Such phenomena are termed *after-images*, and

are accounted for by supposing that the light from an illuminated surface fatigues a limited area of the retina, and that the after-image is due to the changes in the retina which attend its recovery from this fatigue. The three classes of phenomena just described are all examples of optical *illusions*, and must be distinguished from the *delusions* of the insane, which have their origin, not in the sense organ, the eye, but in the brain.

193. *Position of Objects on the Retina.*—In consequence of the bending of rays of light by the refractive media, the image of an external object is inverted on the retina, and yet we see objects erect. The probable explanation is, that the mind may perceive as correctly from an inverted as from an erect image. When we glance at a column from top to base, we move the eyeball downwards so as to bring successive parts on the yellow spot, and it is the feeling of movement which informs us which is top and which is base, not the inverted position on the retina, of which we are really unconscious.

194. *Single Vision with two Eyes.*—This phenomenon is explained by the fact that there are corresponding points on the retina, so that when, by the regular action of the muscles of the eyeball, an image is formed on a corresponding point in each eye, the mind is conscious of one image. If we alter the direction of the axis of one eye by pressing gently on the ball, an image is formed on a point of the retina of that eye which does not correspond, and consequently we squint, or see two images.

Hearing.

195. *General Description of Ear.*—The organ of hearing is composed of three portions, the external, middle, and internal ear. The external ear consists of the *auricle*, which presents elevations and depressions, the functions of which are to receive and reflect the vibrations of the air which constitute sound, and to transmit these by a tube, partly cartilaginous, partly bony, called the *auditory canal* (fig. 106, *a*), to the middle ear. The middle ear is named the *tympanum* or drum, *b*. It is a cavity in the petrous or hard portion of the temporal bone. It is shut off from the auditory canal

by the *membrane of the drum*, a thin structure capable of vibrating when acted on by the vibrations of the air. The tympanum communicates with the back of the throat by the *Eustachian tube*, *c*, the function of which is to equalise atmospheric pressure on both sides of the vibrating membrane. When this tube becomes stopped mechanically by enlargement of the tonsils, partial deafness is the result, and when cleared so as again to allow air to pass into the tympanum, hearing at once returns to its normal state. Across

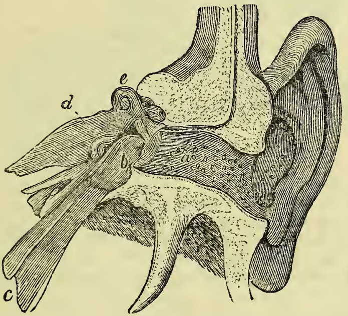

Fig. 106.—General View of the External, Middle, and Internal Ear, shewing the interior of the auditory canal, tympanic cavity, and Eustachian tube: *a*, the auditory canal; *b*, the tympanum; *c*, the Eustachian tube, leading to the pharynx; *d*, the cochlea; and *e*, the semicircular canals and vestibule, seen on their exterior by the removal of the surrounding bony tissue.

the tympanum, we find a chain of small bones, one of which, the *malleus*, or hammer (fig. 107, *m*), is attached by a long handle, *h*, to the drum; this unites by a joint with another, the *incus*, or anvil, *sc*, *lc*; which in turn bears the *stapes*, or stirrup, *s*, the base of this being fixed to a small oval membrane closing an aperture, called the fenestra ovalis, which communicates with the internal ear. The function of this chain of bones, which is really a jointed lever, is to convey vibrations from the membrane to the internal ear.

196. *Structure of Internal Ear.*—The internal ear, or labyrinth, so called on account of its complexity of structure, is the essential

part of the organ of hearing, because here we find the filaments of the auditory nerve which are ultimately to receive impulses originally produced by vibrations of the air, and which are conveyed by the intermediate structures already described. It is made of three parts—the *vestibule*, or central part; the *semicircular canals*, three in number, which communicate by five openings with the vestibule; and the *cochlea*, so called from its resemblance to a snail shell. Each of these parts is excavated from the substance of the bone, and forms the bony or osseous labyrinth; but within this we have a fibrous structure exactly corresponding in shape, the membranous labyrinth. The osseous is separated from the membranous labyrinth by a fluid called the *perilymph*, and within the membranous portion there is another fluid, called the *endolymph*. The terminations of the auditory nerve end in vibratile structures in the membranous portion, and by the presence of the two fluids just mentioned, the most delicate vibrations of the air communicated directly to the drum and chain of bones, or indirectly through the bones of the head, are conveyed to these structures, and by these to the nerves.

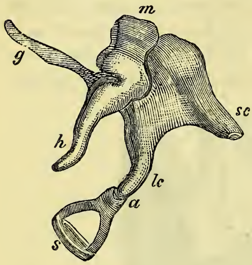

Fig. 107.—Ossicles of the Left Ear, as seen from the outside and below: *m*, head of the malleus; *g*, the slender process, or *processus gracilis*; *h*, the manubrium or handle; *sc*, the short crus, and *lc*, the long crus of the incus; *a*, the position of the lenticular process, through the medium of which it articulates with the head of the stapes; *s*, the base of the stapes.

197. *Structure of Cochlea.*—The structure of the cochlea is very remarkable. It consists of a central pillar, round which a tube makes two and a half coils. This tube is divided into two compartments by a partition, partly bony, partly membranous. The upper portion communicates with the vestibule, and, from its fancied resemblance to a stair, has been called *scala vestibuli*. Suppose we ascended this stair to the apex of the cochlea, we would there find a small opening communicating with the lower compartment, which has been called the *scala tympani*. It received this name because at the bottom it communicates with the tympanum by a round opening, called the *fenestra rotunda*, closed by a thin membrane. The cochlear branch of the auditory nerve enters the base

of the pillar just mentioned, and distributes branches to the membranous portion of the scalæ. But this is not all. Between the two scalæ or staircases, in a triangular space, there is a remarkable

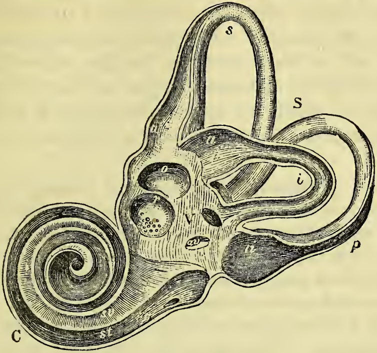

Fig. 108.—Interior of the Osseous Labyrinth: V, vestibule; *av*, aqueduct of the vestibule; *o*, fovea semi-elliptica; *r*, fovea hemispherica: S, semicircular canals; *s*, superior; *p*, posterior; *i*, inferior; *a*, *a*, *a*, the ampullar extremity of each; C, the cochlea; *sv*, osseous zone of the lamina spiralis, above which is the scala vestibuli, communicating with the vestibule; *st*, scala tympani, below the spiral lamina.

organ, called the *Organ of Corti*. This is a complicated structure, which space will not allow us to describe, but essentially it consists of three or four thousand jointed rods, bearing ciliated cells called *hair cells*, which are apparently capable of vibrating. These are connected with auditory nerve filaments. Viewed from above, the organ of Corti presents an appearance somewhat like the key-board of a piano.

198. *Functions of Parts of Ear.*—We know little regarding the functions of the different parts of the internal ear. That they have different functions, we infer from the structure being so dissimilar, and also from the facts of comparative anatomy. In the animal kingdom, the vestibule first appears; to this are superadded the semicircular canals; and lastly, the cochlea, which increases in complexity from the lower orders of the mammalia up to man, in whom it is one of the most complicated organs of the body. The

vestibule probably enables us to experience a sensation of sound as such; the semicircular canals may assist in determining the direction of sounds, or, according to recent researches, may so affect us as to give us the *sense of equilibrium* or of *rotation;* while there are many arguments in favour of the view that the cochlea, as we find it in man, with a highly elaborated organ of Corti, may be the mechanism by which we appreciate the *pitch* and *quality* of musical sounds, which act so powerfully in exciting the emotions.

199. *Range of Hearing.*—The range of hearing, like that of vision, varies in different persons. Some are insensible to sounds that others hear. Many cannot hear the chirp of a grasshopper or the squeak of a bat, two of the shrillest sounds in nature. The range of the ear is much greater than that of the eye in detecting movements which produce vibrations. Thus we hear the sound produced by a vibrating rod or string long after we have ceased to see the movements. The range of the human ear is probably nine or ten octaves. The lowest sound recognisable as musical is produced by about 32, and the highest by about 32,000 vibrations per second.

The Muscular Sense.

200. There is still another sense, called the muscular sense, or sense of weight. If we close our eyes, and hold a weight on the palm of the outstretched hand, we experience a peculiar sensation. It is not referable to any of the five senses, except, perhaps, to touch. But it is not simple touch. We are conscious of an effort to sustain the weight, and of a firm condition of the muscles of the arm. This sensation is the muscular sense. It is the sensation we experience when any groups of the voluntary muscles are called into action, and by it we become aware of the condition of these muscles. By means of this sense, we stand erect, we walk, balance ourselves on a narrow ledge, throw stones or weapons, play on many instruments, &c.; and it adds largely to our feelings of pleasure. It is chiefly by means of the muscular sense that we receive our notions of solidity, relief, and of things being external to, and at a certain distance from, ourselves.

VOICE AND SPEECH.

201. There is a difference between *voice* and *speech*. Voice is a sound produced by vibrations of two thin folds of membrane called the vocal cords, placed in the larynx, at the top of the trachea or windpipe : *speech* is the modification of voice into sounds connected with certain ideas produced by the action of the brain, which we wish to communicate to our fellow-men. Many animals have voice; none, except man, have articulate speech expressive of ideas. The organ of voice is the *larynx* (behind the *Pomum Adami*), the structure of which is complicated, and cannot be here described. It consists of various cartilages and muscles, the object of which is to tighten or relax the margins of two folds of membrane, called the *vocal cords*. By the vibrations of these cords voice is produced, and by tightening or relaxing, separating or approximating them, we obtain various modifications of voice. When a high note is sounded, the cords are tense and close together (fig. 109); and, on the contrary, when we sing a deep bass note, they are relaxed and wide apart. The quality and compass of the voice differ in individuals. In men, the highest is the tenor; the lowest, the bass; the intermediate, the barytone. In women, the corresponding notes are the soprano, the contralto, and the mezzo-soprano. The difference between the deep bass of a man and the shrill soprano of a woman, is, that in the man the cords are longer and less tense than in the woman.

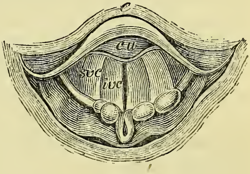

Fig. 109.—Condition of the Larynx during the emission of a high or acute sound: *e*, epiglottis; *cu*, cushion of epiglottis; *ivc*, true vocal cord; *svc*, false vocal cord.

202. Speech is voice so modified by the action of the throat, tongue, cheeks, and lips, as to mean or indicate objects, properties, ideas, &c. This is language. If we breathe quietly, without causing the vocal cords to vibrate,

and modify by the action of the mouth, &c. the volume of air expelled, we produce *whispering*.

THE FUNCTION OF REPRODUCTION.

203. The third great function of animal life is reproduction, by which the species is perpetuated. It is beyond the scope of this work to treat of this subject in detail, but it may be briefly stated that three modes of reproduction may take place. These are:

Abiogenesis, or the production of beings without any parent. This mode, sometimes termed *spontaneous generation*, is denied by all but a very few, and if it do occur, it is only amongst the very lowest forms of animal or vegetable life.

Parthenogenesis, or the production of a series of offspring, often of various forms, as the result of *one* sexual act. This mode of reproduction, sometimes known by the term *alternation of generation*, occurs among many polypes, worms, and in the *aphides*, or plant-lice.

Homogenesis, or the production of offspring from a germ or germs formed by a female, and fecundated by a male parent. Sometimes both male and female organs exist in the same individual, which is then termed a *Hermaphrodite*. Homogenesis is the highest and most differentiated mode of reproduction.

ANIMAL HEAT.

204. All the processes hitherto described, whether physical or chemical, contribute to produce heat. The great source of heat in the body is the oxidation processes which take place in almost every tissue and in every organ. The circulating blood acts as a conductor or distributer of heat, so that the uniform temperature is about 98·4° Fahr. It is much the same in other mammals, but it is higher in birds. Animals, such as man, which maintain a constant temperature, are called *warm-blooded*, while those which have no constant temperature, and have a temperature usually only

a few degrees above that of the medium in which they live, are called *cold-blooded.* The body is always losing heat by radiation and conduction. To maintain the body at a uniform temperature, whatever that of the outside medium may be, arrangements are made by which the amount of heat eliminated and the amount of heat produced are kept at a balance. Thus by the use of clothes, by the activity of the skin, by the nature of the food, and by the amount of muscular exertion, the heat is maintained and regulated.

LIFE.

205. It is impossible to define what life is. Many attempts have been made, and probably the most successful is that of Béclard: 'Life is organisation in action.' The word life suggests *vitality*, and physiologists frequently speak of vital forces, or vital actions. By a vital action is meant simply an action which we cannot explain by any chemical or physical laws at present known. The time may come when some phenomena now considered vital may be so explained. These vital phenomena, at present unexplained, may be thus enumerated: (1) *differentiation in growth,* that tendency which an ovum has, by hereditary peculiarities, to develop into a particular kind of animal, or that tendency which causes the apparently similar cells of the embryo to develop into the various kinds of tissues; (2) *contractility*, the property of muscular fibre; (3) *sensibility*, the property of nervous tissue. Lastly (4), *mental acts*, including sensation and volition. Now it must be pointed out that we are acquainted with many of the physical conditions of these phenomena, but not with all. When we know all the physical conditions, then we shall not speak of them as *vital* phenomena. Even at present no scientific physiologist assumes the existence of a 'vital force' as distinct from other forces, but he contents himself by stating that there are various phenomena which in the present state of science he cannot explain by known chemical or physical laws.

206. It may be noted also that in an individual we find different manifestations of life. Thus we have the life of each independent cell or fibre, the life of each organ, and lastly the life of the whole individual, or *somatic* life.

DEATH.

207. Death is the cessation of all vital phenomena, without the capability of resuscitation. During the whole of the lifetime of an individual there is death in one sense occurring here and there throughout the body. Each tissue is developed, grows to maturity, performs its functions, decays, and dies. Probably no tissue lasts throughout the whole of the somatic life. Thus the cells of the blood are continually changed. Again hairs, nails, feathers, and teeth have each a certain period of existence, at the termination of which they die and separate from the rest of the body. At last, however, a time comes when the general death of the body takes place. This is what we usually term *death.* It results from failure either of the action of the heart, of the lungs, of the brain, or from death of the blood, as in cases of severe septic poisoning. Death beginning at the heart (*fainting*) is termed *syncope*, at the brain, *coma*, and at the lungs, *asphyxia.* When the action of the heart becomes weaker and weaker until it ceases to beat, either from feebleness of its walls, or from poisoning by carbonic acid or want of oxygen, in consequence of a state of asphyxia, death is said to occur by *asthenia.* After *somatic* death, the tissues may live for a short time, but they gradually die one by one. Muscular irritability disappears, and the muscle stiffens from coagulation of its substance. This rigid state, the 'stiffness of death,' is called *cadaveric rigidity.* After a time the rigidity passes off, the muscles and other tissues become soft, and the body, subjected to the physical and chemical agencies of nature, is resolved into the elements of which it was at first composed.

QUESTIONS.

Section 3, 4. Describe a vertebra, and point out the peculiarities which distinguish a cervical from a dorsal vertebra.

6. Enumerate the bones entering into the formation of the skull.

8. What varieties of skulls are met with in the human race?

9. Describe the framework of bones forming the thorax. What is the use of the cartilages which join the ribs to the sternum?

10. Enumerate the bones found in the upper extremity. How would you know the right from the left radius?

11. Describe the general structure of the pelvis, mentioning the bones which enter into its formation. How is the foot adapted for stability?

12. Mention the points in the structure of the human skeleton which adapt it for the erect position.

13. What are the different varieties of joints? Describe the structures entering into the formation of such a joint as the elbow-joint. How are the bones of the skull fixed together? What is the structure of the joint which permits of the movements of the head on the top of the vertebral column?

14. What structure forms what we term the 'flesh' of a limb? What varieties of muscles, as regards physiological action, are met with in the human body? What do you understand by supination and pronation? What is the permanent condition of the fore-leg of a dog?

16. What orders of levers are met with in the human body?

19. What advantage is gained by levers of the third order where the power is inserted near the fulcrum? Classify the levers of the body according to their physiological purpose.

21. Why does the head drop forwards during sleep? How is a man enabled to stand upright for a considerable time with little muscular fatigue?

22. Describe the movement of walking, and contrast it with that of running. Indicate generally the position of the principal organs in the abdominal and thoracic cavities.

23. What is the meaning of 'Histology?' What instrument is necessary in histological work? What do you understand by the phrase, 'a magnifying power of 250 diameters linear?'

24. Give an example of a structure formed by aggregation of molecules. Mention a physical condition which apparently affects the form of bodies produced by molecular aggregation.

25. Enumerate various kinds of molecular movement. How could you demonstrate 'Brunonian' movements, and why are they so called? Can you explain why a frog found in a corn-field may be of a pale yellow colour, while one found in darkness is usually of a dark-brown? What is the physiological bearing of Mr Lister's investigations on pigment cells?

26. Describe the parts of a typical cell.

28. Draw and describe the form of various cells.

29. What is protoplasm?

30. What do we know regarding the chemical constitution of cells?

31. What phenomena are manifested by living cells? What is one of the most remarkable phenomena of inflammation? How does the growth of a cell differ from the growth of a crystal? What is the amœba? Compare its actions with those of a similar structure found in the body.

32. What are the conditions necessary for cell-life?

33. How could you readily demonstrate to children the growth of cells by budding? By what various modes may cells multiply?

34. Classify the varieties of cells met with in the human body.

35. What do you mean by epithelium and endothelium? Describe the microscopical appearance of a drop of saliva. Draw the form of the varieties of epithelial cells.

36. Where is endothelium met with, and how may it be demonstrated?

37. Describe ciliary motion, and mention how you could readily shew it to a class of children.

38. Mention the localities in the body where pigment is found. What is an albino? Why have white rabbits usually 'red' eyes?

39. Describe the microscopical appearance of fat. What are the uses of fat?

40. What are the varieties of fibres met with in the body?

41–42. What are the microscopical appearances of white fibrous and elastic tissues, and why are they so called? How could you quickly detect fibres of elastic tissue mixed up with those of white fibrous tissue?

44. Where is involuntary muscle found?

45. Describe the structure of striated muscle.

46. What is the chemical composition of muscle? What is the cause of *rigor mortis?* Why does a muscle become acid after severe work?

47. What is the special vital property of muscle? By what various methods may a muscle be stimulated? What is the natural stimulus of a muscle?

48. How does a muscle produce mechanical movement? What is the meaning of the phrase, 'period of latent stimulation?' Is there any definite relation between the amount of work performed by a muscle and the amount of stimulation? If not, why not?

49. What is the meaning of 'muscular fatigue?' What is cramp or tetanus?

50, 51. What physical phenomena are exhibited by muscle at rest and in a state of activity?

51. How may the electrical condition of living muscle be demonstrated? What change occurs in this condition during action, and what is this change called?

52. Distinguish between the optical appearance of a tube and of a fibre when viewed under the microscope.

53. Describe the appearance of fresh cartilage when seen by the naked eye, and when a thin section is placed under the microscope.

54. Enumerate the varieties of cartilage.

55. Describe the microscopical appearance of a thin section of bone, and contrast a longitudinal with a transverse section. How is a bone nourished?

56. Describe the changes in the growth of a bone. What is the function of periosteum?

57. What is the chemical constitution of bone?

58. Enumerate the chief elementary chemical constituents of the body.

59. What are the chief inorganic compounds found in the body? How much common salt exists in an average human body?

60, 61. What are the chief organic compounds? Give examples of nitrogenous and of non-nitrogenous compounds, stating the source of each. What do you understand by the term 'albuminous derivatives?' Give examples. What varieties of sugar are met with in the body? What is the chemical composition of a 'fat?' Give examples of substances found in the body constructed on the type of an alcohol.

62–66. Describe the chemical changes occurring in the living body. Why is it so difficult to investigate these chemical changes?

67. Give examples of ferments found in the body. What processes analogous to fermentation occur in the body?

69. Describe generally the process of nutrition.

71. Why is it necessary to take food?

72. What is the composition of the atmosphere? What is the physiological importance of the atmosphere?

73. What is the physiological importance of water?

74. Classify the proximate constituents of food, and give an example of each.

75. What conditions determine the amount of food?

76. What is the average amount of dry food required by a hard-working labourer in twenty-four hours? How much water must be combined with the food?

77. On what circumstances does the nutritive value of food depend? Contrast the composition of various articles of food mentioned in the table on page 61, and shew how, by combining two or more of these, a nutritive diet may be formed.

78. Describe the process of mastication. Enumerate in proper order the teeth in the human adult. Describe the structure of a tooth.

79. What are the nerves of the tongue?

80. Describe the structure of a salivary gland. What are the chemical composition and functions of saliva?

81. Describe what is known regarding the innervation of the salivary glands.

82. Describe the process of deglutition. How is the food prevented from getting into the windpipe during swallowing? What is the mechanism of a simple reflex action?

83. What are the nerves concerned in deglutition? Enumerate the parts of the human alimentary canal in their proper order, beginning at the mouth.

86, 87. Describe the structure of the human stomach.

88–90. What changes occur on food in the stomach? What is the composition of the gastric juice?

92. Describe what occurs in the stomach after a glass of milk has been swallowed.

94. What are the conditions favourable for good digestion?

95. Describe the process of rumination.

98. Describe the naked eye and microscopical appearance of the mucous membrane of the bowel.

102–104. What are the functions of the bile, pancreatic juice, and intestinal juice as regards digestion?

105. What materials are ejected from the body in the fæces?

106. What is chyle? Describe its microscopical appearance. By what channels does the chyle enter the blood?

108. Enumerate the various sources from which blood is formed.

109. Enumerate the blood-glands. Why do they receive this name?

110. What is lymph?

111. What are the principal points of interest in the microscopical structure of the spleen?

113. Describe the microscopical appearance of a drop of human blood, and contrast it with that of a camel, a hen, a frog, and a fish.

115. Describe the phenomenon of the coagulation of the blood.

117. Describe the structure of capillary blood-vessels. What are their functions?

118. Give a description of the cavities of the heart in their physiological order.

119. What do you mean by the terms 'pulmonary and systemic circulations?'

120. How is the blood prevented from passing backwards from ventricles to auricles?

120–126. Enumerate the various forces concerned in the circulation of the blood.

123–128. What function does the elasticity of the greater blood-vessels perform in the circulation? How is the 'pulse' produced? How often does it beat per minute (1) in early infancy; (2) in old age; (3) in middle life? What other circumstances affect it?

130. Describe what is known regarding the innervation of the heart. What do you mean by the term 'vaso-motor?' What is the function of the 'depressor' nerve?

131. What is respiration?

134. Describe the ultimate structure of a portion of lung.

135. How is the air introduced into the chest, and how is it expelled?

136, 137. What varieties of respiration are met with as regards sex and age? What is the ratio between the number of respirations and the number of pulsations per minute?

138. Describe the meaning of the term 'vital capacity.'

139. Illustrate the bearings of a knowledge of respiration on theories of ventilation.

140. What is the 'respiratory system of Bell?'

141. What are the conditions of healthy nutrition? What is growth?

142. Upon what conditions does healthy secretion depend? Draw a plan of a simple secreting structure, and shew how it may be modified into the various kinds of glands.

143. What is meant by 'excretion' as distinguished from 'secretion?'

145. Describe the minute structure of a lobule of the liver.

146. What are the functions of the liver?

147. What is the glycogenic function of the liver?

148. Give the qualitative composition of bile.

149. Describe the appearance of a vertical section of human skin, mentioning specially the appearance of the two kinds of glands.

150. What is perspiration? How is it carried off from the surface of the body?

151. What are the functions of the skin?

152. What structures are seen with the naked eye when a kidney is cut open longitudinally? How are the blood-vessels of

the kidney related to the uriniferous tubules? Illustrate this by means of a diagram.

153. Give the composition of healthy human urine.

155. What conditions influence the amount of urine secreted?

160. What is the naked eye appearance presented when a thin slice is cut off the surface of a sheep's brain, and when a spinal marrow is cut across?

161. Shew by a drawing the minute structure of a nerve.

162. What are the varieties of nerve-cells met with in the nervous centres? Draw the various forms.

163. What is the rapidity of the nerve-current?

165, 166. What is the difference, as regards position, between the nervous system of an invertebrate and that of a vertebrate animal? Enumerate in order from before backwards the ganglia in the brain of a vertebrate. Contrast the brain of a frog with the brain of a pigeon.

166–168. What are the functions of the convolutions of the brain? What are the chief points of difference between the brains of a cat or dog and of a man?

168. Mention generally the functions of the great ganglia forming the brain.

169. Suppose an exposed nerve, the functions of which are unknown, be irritated, what possible results may follow, and why? What is the difference physiologically between a nerve of general, and of special sensibility?

170. Enumerate the cranial nerves from before backwards, stating the chief functions of each.

171. What are the functions of the spinal cord? Explain why injury to one side of the brain may cause paralysis on the opposite side of the body. What would be the effect of cutting half-way through one lateral half of the spinal cord?

172. What are the general functions of the sympathetic system of nerves?

173. What are the organs of touch in the skin?

174. What organs have recently been discovered which may be regarded as the terminal organs of taste?

175. Draw the structures found in the upper part of the nose connected with the sense of smell.

176. Through what transparent structures must a ray of light pass before it reaches the retina of the eye ?

180. What is the structure of the iris ? What are its functions ?

182, 183. Describe the appearance of a vertical section of retina. What part of it is really sensitive to light ? How is this part connected with the optic nerve ?

188. Describe the apparatus for the secretion of tears. How can you explain physiologically the copious secretion of tears following mental emotion, or the application of an irritant to the eye ?

189. Explain generally the mechanism of vision.

190. How is the eye accommodated for distinct vision at different distances ?

191. Is the eye a perfect instrument optically ? If not, what are its defects ?

192. Mention the chief subjective phenomena of vision.

195. What are the parts forming the organ of hearing which can be seen with the naked eye ?

197. Describe generally the structure of the cochlea, and mention what its functions probably are.

198. What functions have been ascribed to the semicircular canals ? By what apparatus do we appreciate musical sounds ?

199. What are the physical conditions of a musical sound ?

200. What do you understand by the muscular sense ?

201. What is the general mechanism of the organ of voice ? What is the condition of the larynx in singing high and low notes ? What are the varieties of the human voice ? What is the difference between voice and speech ?

202. How is the condition called whispering produced ?

203. What are the various modes of reproduction ?

204. What are the sources of animal heat ? Mention also the temperature of the human body.

205. What are the conditions usually termed 'vital phenomena ?'

207. What is death ? What do you understand by the terms 'molecular' and 'somatic' death, and what are the immediate causes of the latter ?

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